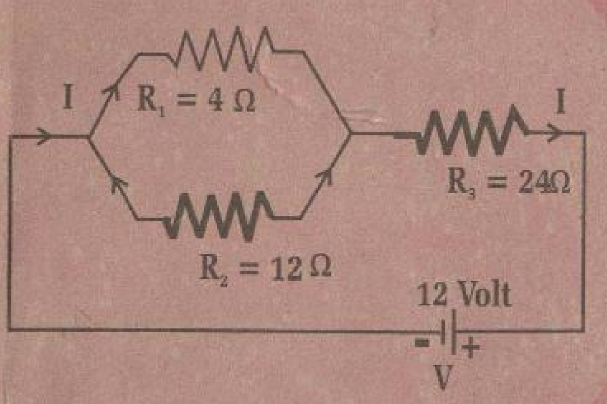
PHYSICS

For Class 10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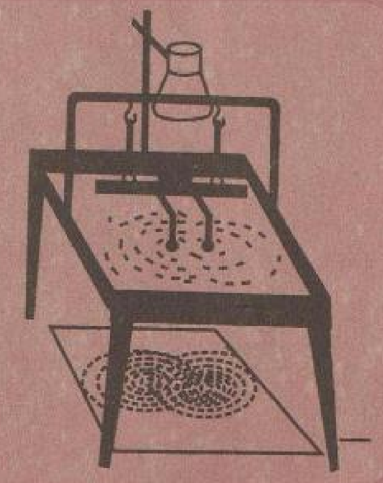

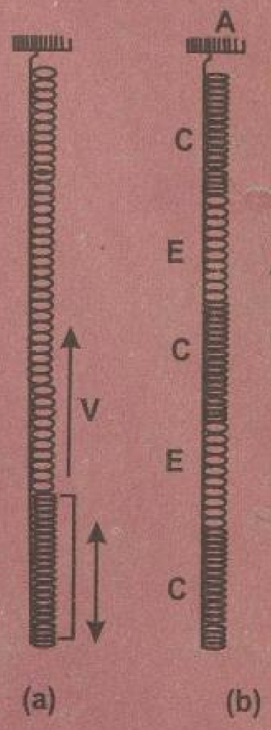

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Chapter 12

OSCILLATIONS AND WAVES

In this chapter you will study

- Oscillations or vibrations
- Periodic motion, its frequency and time period
- Simple harmonic motion: definition and characteristics
- Simple pendulum and its oscillations
- Oscillations of a mass attached to a spring
- Waves: transverse and longitudinal waves
- Waves as carrier of energy
- Ripple tank
- Reflection, refraction, diffraction and interference of waves
- Standing waves and their properties

12.1 Introduction

You must have wondered how sound reaches our ears. Why do we fix a TV antenna on the top of a roof? How does light from the sun and other stars reach us? The answer to all these questions lies in the study of waves.

In this chapter we shall study oscillations (vibrations) which initiate waves, propagations of waves in a material medium and the manifestation of waves as sound.

12.2. Oscillations

Figure (12.1) shows a simple pendulum, a steel strip fixed in a clamp and a mass suspended from a spring. Displace slightly the bob of the pendulum to a side, from its normal position and then release it. You will observe that the bob begins to oscillate about its normal or mean position. Similarly, displace the steel strip slightly from its mean position and let it free. The strip begins to vibrate about its mean or equilibrium position. Now pull down slightly the mass attached to the spring and release it. The mass-spring system begins to oscillate up and down about a mean position.

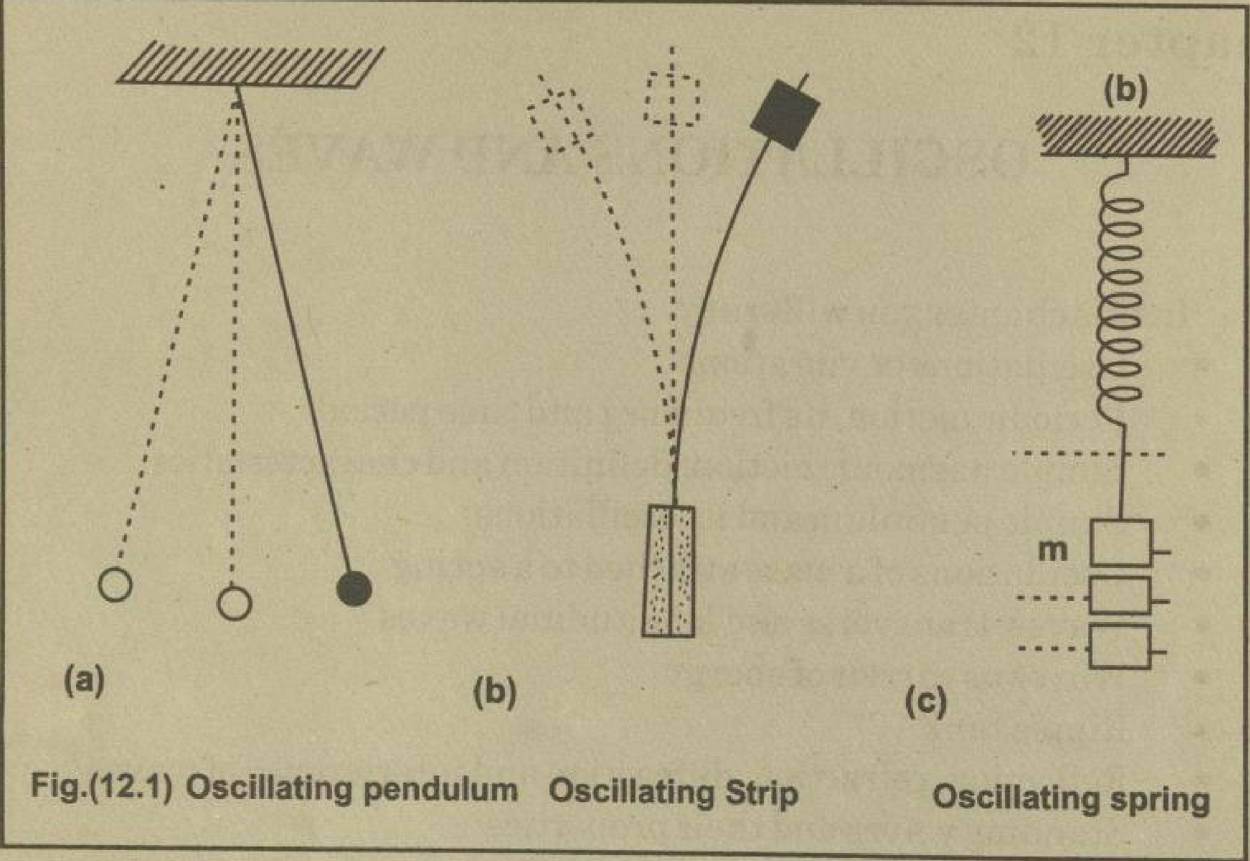


Fig.(12.1) Oscillating pendulum Oscillating Strip Oscillating spring

The activities given above are only three examples of a vibratory motion. A vibratory motion is a general phenomenon and is intimately related to the elastic property as well as the inertial property of matter.

12.3 Periodic Motion

Any motion that repeats itself in equal intervals of time is called periodic motion. The second's hand of a watch repeats its motion on the dial in every 1 minute. In 24 hours the earth completes its periodic rotation around its axis. In fact, every vibratory motion is periodic. The motion of a simple pendulum and the oscillations of a mass attached to a spring are periodic motions. It can be shown that every periodic motion, however complicated it may be, can always be resolved into simple oscillatory components. The simplest periodic vibratory motion is called simple harmonic motion and is discussed, in the following section.

12.4 Simple Harmonic Motion

Simple harmonic motion (S H M) is an ideal vibratory motion. By definition, SHM is that linear motion in which a body, once displaced from its mean position O, so oscillates about O under the influence of a force F which is always directed towards O and is directly proportional to the displacement of the body from the mean position. Mathematically if x is the displacement of the body from the mean position and F is the central restoring force F then

$$F\alpha(-x)$$

or
$$F=-kx \qquad (12.1)$$

where k is the constant of proportionality. The negative sign means that the force is always towards O and is opposite in direction to the displacement x. The force F is mass m times the acceleration 'a' of the body. So, Eq. (12.1) can be written as

$$F= ma$$

Therefore, $ma=-kx$

or,
$$a=-\frac{k}{m}x \qquad (12.2)$$

that is, acceleration (- displacement) (12.2')

According to this equatin, SHM can also be defined in terms of the acceleration of the oscillating body:

imple harmonic motion is the type of motion of a body in which the acceleration is always proportional to but opposite in direction to the displacement of the body from its mean equilibrium position.

If x is to the right of O, then a is directed to the left. If x is negative and is to the left of O, then a is directed to the right toward O. A body executing a SHM is called a simple harmonic oscillator (SHO).

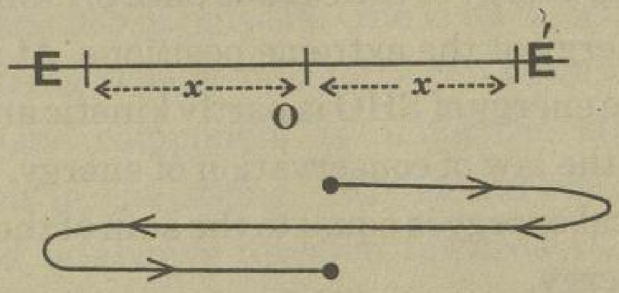


Fig.(12.2) Illustration of simple harmonic motion

As shown in Figure. (12.1), the swinging of a simple pendulum towards its mean or vertical position is an example of simple harmonic motion. Similarly the vibrations of the steel strip and the up and down motion of a mass attached to a spring are examples of SHM. You can observe a variety of other motions that are almost SHM. Keeping in view these observations and the definition of SHM, we can define and determine a few characteristics of SHM.

i) In SHM, a body oscillates about a central or mean position O. See Fig. (12.2)

ii) SHM is always in a straight line. The displacement x is always between two extreme positions E and É. E and É are at equal distance from the mean position O. The distance between OE or O É is known as amplitude of simple harmonic motion.

iii) A restoring force F is always acting upon the SHO. Force F is always directed towards the central point O. Acceleration produced by F is also always towards O.

iv) The acceleration $a = \frac{F}{m}$ is directly proportional to the displacement x of the body from O. The force and the acceleration are maximum at the extreme positions and are zero at the mean position

v) The velocity of the SHO is maximum at the mean position. It decreases as the body moves away from O. At the extreme positions E and É, the velocity of the SHO is zero.

The energy of the SHO is entirely kinetic at O and is entirely potential energy at the extreme positions. At any point between O and E or É, the energy of SHO is partly kinetic and partly potential. But according to the law of conservation of energy, the total energy is constant. The total energy is equal to the sum of the kinetic energy and the potential energy.

vi) The time period of a simple harmonic motion (SHM) is generally denoted by T. It can be proved that time period of a SHM is given by

$$T = 2\pi\sqrt{\frac{m}{k}} \qquad (12.4)$$

We shall now define some terms used in connection with SHM.

Vibration: A vibration means one complete round trip of the body. In Fig. 12.2, it is the motion of mass 'm' from E back to E, or from E' back to E', or from O to E to E' and back to O.

Amplitude: It is the maximum displacement of the body on either side of its equilibrium position.

Time Period: It is the time required to complete one vibration or oscillation. The time period is measured in seconds.

Frequency: It is the number of vibrations executed by a oscillating body in one second .In S.I units, frequency is expressed as vibration s^{-1}, cycle s^{-1}, or hertz (Hz)

The frequency f and time period T are related by the equation

$$f = \frac{1}{T} \qquad (\text{as } f\ T = 1) \qquad (12.5)$$

The frequency is given by the reciprocal of the period of oscillation

12.5. Simple Pendulum

An ideal simple pendulum consists of a mass suspended by a weightless and inextensible string from a fixed support. In practice, the mass is a small metallic bob suspended by a fine string as shown in Fig (12.3)

If we displace the bob from its mean position E and allow it to go, it will move towards O under gravity. In fact it starts oscillating about O.

Two forces are always acting on the bob of mass m. One is its weight **mg** and the other is the tension in the string. The weight force can be resolved into two rectangular components. One component is along the string in a direction opposite to the tension in the string. The second component is perpendicular to the string and is always directed towards O. The first component balances the tension is the string and there is no motion along the string. The second component of the weight is horizontal and directed towards the mean position O. It is this component which produces oscillations of the pendulum. When the bob is released at rest at the point E, the effective component of the weight produces in it acceleration towards O. At E, the force acting on the bob and the acceleration are maximum.

On the way from E to O, the acceleration gradually decreases and becomes zero at O. Here the velocity gained is maximum. Therefore, due to inertia, the bob does not stop at O. It moves towards the point E' with a decreasing velocity and becomes zero at E'. Due to gravity, the bob will then fall back from E' to O. Once again, the bob will not stop at O but continues to move towards E.

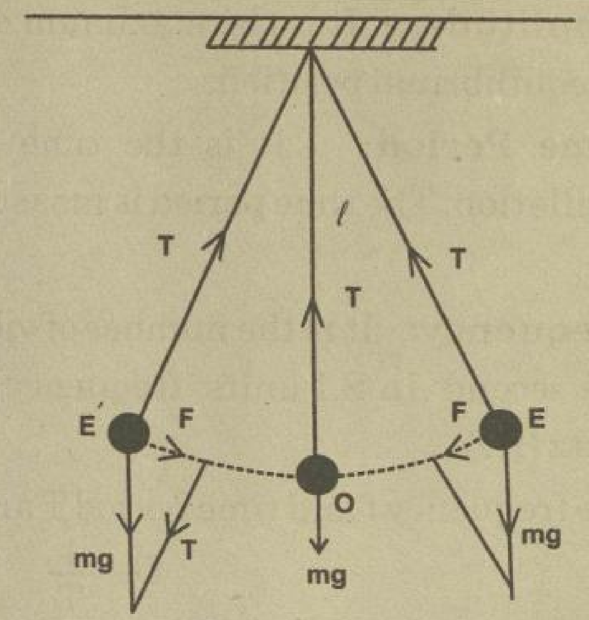


Fig.(12.3) Forces acting on a simple pendulum, F is restoring force

This process is repeated again and again and the bob continues to oscillate between extreme positions E and E'

It is evident from the above discussion that in simple pendulum the acceleration is directly proportional to the displacement and is directed towards the mean position. Therefore, the motion of a simple pendulum can be considered as SHM. The bob of the pendulum behaves as SHO.

You know that the maximum displacement of a vibrating body from its mean position is known as the amplitude of the body. In the case of a simple pendulum, shown in Fig.(12.3), the amplitude is OE or OE' One complete round trip of a vibrating body is called one vibration. In case of simple pendulum, the motion of the bob from one extreme position E to other extreme position E and back to E is one vibration. The time to complete one vibration is known as the time period T.

If the amplitude of the motion is small compared with the length l of the pendulum then the time period T of the pendulum is given

$$T = 2\pi\sqrt{\frac{l}{g}} \qquad (12.6)$$

where g is the acceleration due to gravity at the location of the experiment.

It is worth noting that according to Eq.(12.6), the time period of the "small" oscillations of a simple pendulum neither depends on the mass of the pendulum nor on the "small" amplitude of the oscillations.

A pendulum is called second's pendulum if it takes two seconds to complete one oscillation. It is used in clocks to record time.

Example 12.1. Find the length of second's pendulum at a place where g = 9.8 ms^{-2}.

Solution:

The time period of a simple pendulum of length 'l' is given by

$$T = 2\pi\sqrt{\frac{l}{g}} \qquad T = 2s$$

$$T^2 = 2\pi^2\frac{l}{g} \qquad g = 9.8ms^{-2}$$

$$\Rightarrow l = \frac{g}{4\pi^2}T^2 \qquad l = ?$$

Put the given values in the above expression

$$l = \frac{9.8ms^{-2}}{4\times(3.14)^2}\times 4s^2$$

$$l = 0.992m$$

12.6 Oscillations of a Mass Attached to a Spring

Every elastic body is set into vibrations by displacing it slightly from its normal state of equilibrium. For example, when a spring is slightly stretched or compressed and is then released, it will start oscillations. You will now come to know that the small oscillations of a mass attached to a spring are simple harmonic oscillations.

Fig. (12.4) shows a spring whose one end is attached to a fixed support and the other end is hanging freely. The spring has a natural length l_o when no load is suspended from its free end.

In Fig.(12.4b), a mass m is suspended from the free end. The weight of the mass pulls the spring. The spring stretches from l_o to l. The spring and the mass suspended from it are in equilibrium. The weight **mg** of the mass and the tension T_o in the spring are equal in magnitude but opposite in direction.

Let us discuss how the mass m oscillates about the mean position. When the mass m is released from rest at the extreme position E, then the initial force acting on the mass is ($-kx_o$). The mass m moves towards O with decreasing acceleration and increasing speed. During this motion, the force acting on m is ($-kx$) where x is the instantaneous displacement from the mean position O. At O the acceleration is zero and the speed is maximum. The moving mass does not stop at O. Because of inertia, the mass m continues to move above O. The spring is now compressed.

The restoring force, once again, comes into play. The restoring force as well as the corresponding acceleration is now directed towards O. The velocity is gradually decreased until the mass stops momentarily at the extreme position E', Fig.(12.4c). Under the action of the restoring force, the mass m moves towards O. On reaching O, its speed is maximum and because of inertia, the mass m over-shoots its equilibrium position O. Eventually, it reaches E and is then ready for the next vibration. This process continues and the mass m attached to the spring oscillates in a simple harmonic manner. At all stages of the motion, the force acting on the mass and the

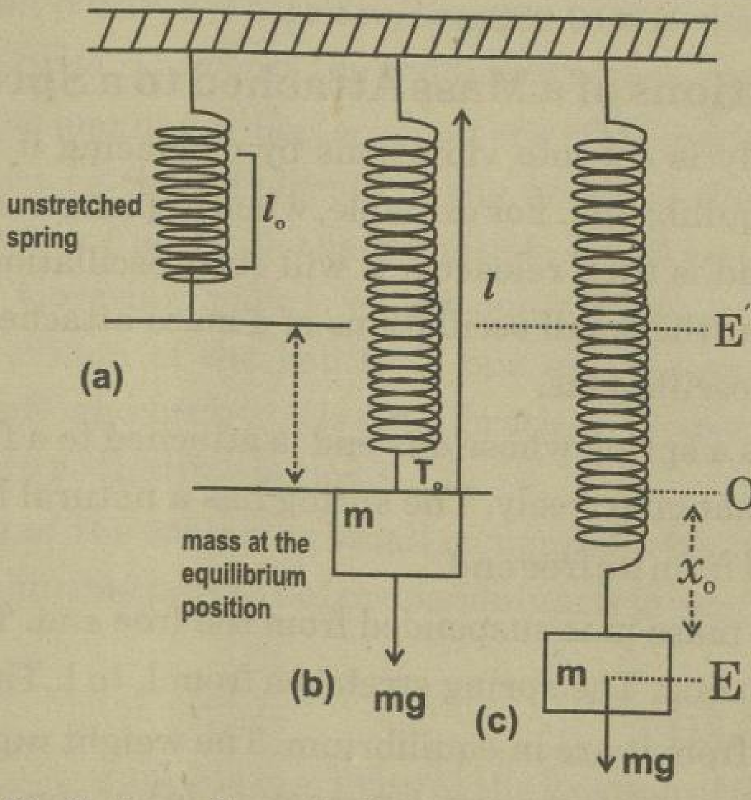


Fig.12.4 Oscillations of a vertically suspended mass-spring system

acceleration produced in the mass are always directed towards the mean position and are proportional to the displacement of the mass from the mean position.

In analogy with equation for the simple pendulum, the formula for the time period T of the oscillations of a mass m attached to a spring is given by

$$T = 2\pi\sqrt{\frac{m}{k}} \qquad (12.8)$$

The frequency of these oscillation is given by

$$f = \frac{1}{T} = \frac{1}{2\pi}\sqrt{\frac{m}{k}} \qquad (12.8)$$

Example 12.2 A mass of 400 grams is suspended vertically from a fixed spring. The system was set into simple harmonic oscillations of frequency 12 hertz. Find the time period of the oscillations and the constant of the spring.

Solution:

Mass = m = 400 g = 0.4 kg

Frequency = f = 12 Hz

Time period: T = ?

Spring constant: k = ?

$$T = \frac{1}{f} = \frac{1}{12}\,s = 0.083s$$

$$T = 2\pi\sqrt{\frac{m}{k}} \quad \Rightarrow k = \frac{4\pi^2 m}{T^2}$$

Substitute the given values in the above equation, we get

$$K = \frac{4\times(3.145)^2\times 0.4\text{kg}}{(0.0835)^2} = 2.3\times10^3\text{Nm}^{-1}$$

12.7 Waves

You must have dropped a stone into a pool of water. A disturbance is created where the stone enters the water. The disturbance is not confined to that place alone. It spreads out in the form of circular wavelets on the surface of water. The water does not itself move outward from the point of disturbance. It merely rises and falls locally. Observe the motion of pieces of paper floating on surface of water. One can see the rise and fall of the water. When a wave reaches a floating object, the object begins to vibrate up and down. Their vibratory motion stops when the wave passes by the floating object. The floating objects do not move with the waves. They simply vibrate locally. The vibration of the floating object is due to the vibratory motion of the particles of water. So, when a wave propagates on the surface of water, it sets the particles of water into vibratory motion. These particles set into motion neighboring particles. They in turn produce similar motion in others and so on until the disturbance reaches particles at the edge of the pool. In this entire disturbance no particle moves from its initial position. Only the disturbance moves through the water, which, acts as a medium for propagation of waves.

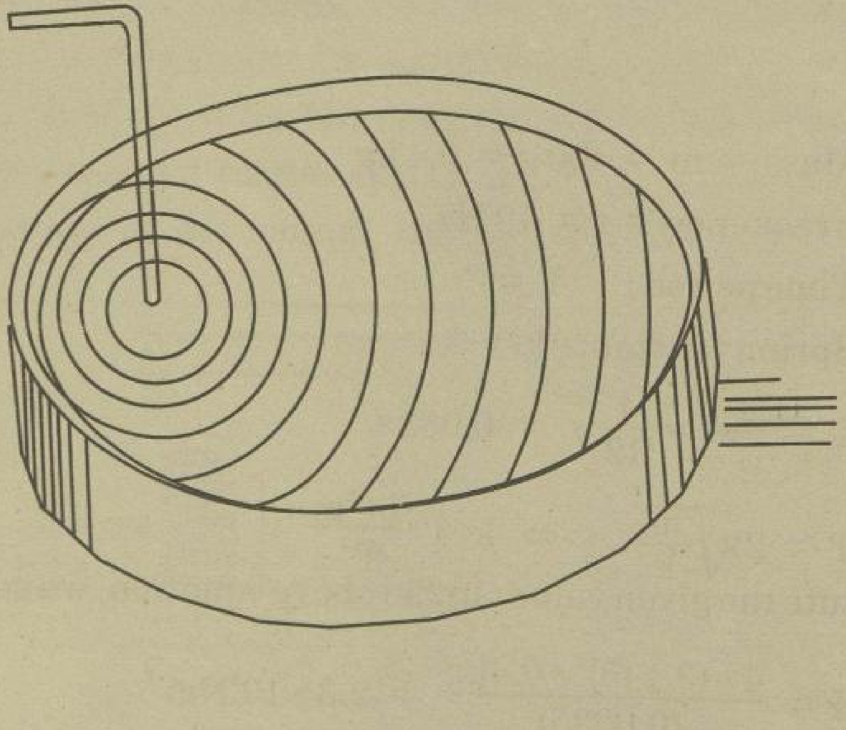


Fig. (12.5) Waves on surface of water

Instead of dropping a stone into a pool of water, you can perform a similar kind of experiment by disturbing water continuously and regularly at a particular location. For example, dip one end of a pencil at the edge of a large tub filled with water. Move the pencil rapidly up and down. Ripples of waves are generated and move outward from the place of disturbance.

Observe the movement of pieces of paper, which are equally spaced and are placed on surface of water. The pieces move up and down about their mean positions. They are not displaced forward from their original positions along with the waves. All the pieces of paper do not vibrated together. They are set into vibration on its own respective turn.

Waves can be produced and propagated in solids as well. Take a long string and mark it with colours at equal spacing. Attach one end of the string to a hook in a wall. Hold the other end in your hand and stretch the string tight in the horizontal position. Now give a small sudden vertically upward jerk to the end of the string and bring it back to its initial position. You will see that a pulse shape wave is formed which travels along the rope.

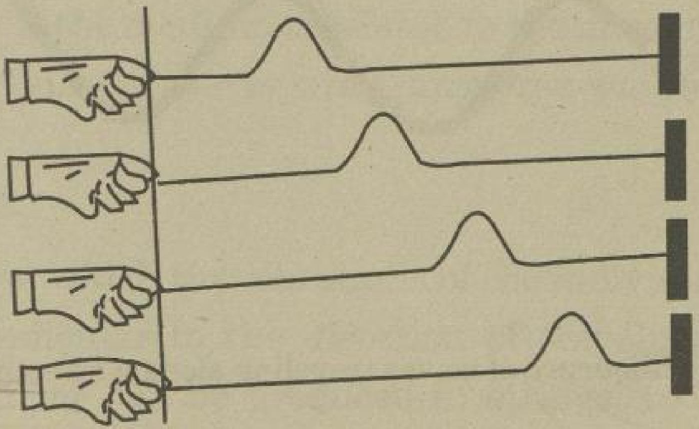


Fig.12.6 Ripples travelling along a stretched rope

Now, instead of giving a single jerk to the end of the string, move it up and down continuously and regularly. You will see that a number of continuous waves are produced. Such a set of waves is called a wave train. If the coloured markings are carefully observed, as the waves travel down the string, you will see that they are vibrating about their mean positions. At a particular time, it can be observed that the markings are in different positions along their vibratory path, rather than vibrating all together. Some parts of the string are above mean position whereas an adjacent part of the string is below the mean position. The part of the wave where the string (medium of propagation) is above the mean position is called the *crest of the wave.* The adjacent part, which is below the mean position, is called the *trough of the wave.* A wave train comprises of alternate crests and troughs propagating in a medium of propagationsuch as the solid strings. The vibrating parts of the string have local up and down motion and are not moving along with the string. Energy is transported, particle-to-particle, by the propagating wave.

12.8 Waves as Carriers of Energy

There are three principal methods by which energy is transferred from one place to another.

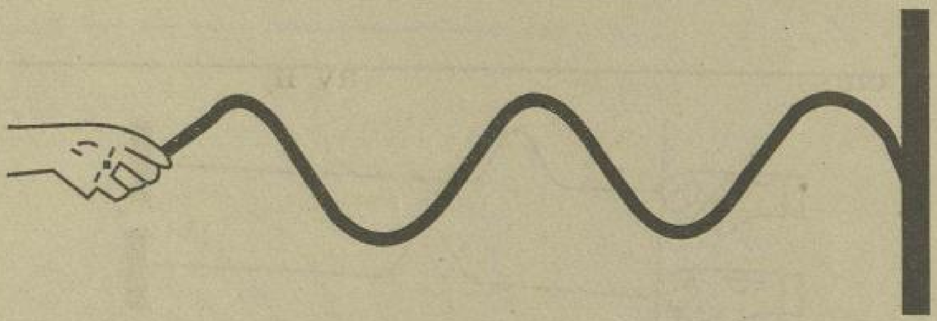


Fig.12.7 Sequence of waves traveling along a stretched rope

i. Motion of a macroscopic body

ii. Particle transmission

iii. Wave motion.

Energy carried by a moving truck, a projected stone, blowing winds, waterfalls and ocean tides are examples of the first method of transportation of energy from one place to another.

The transfer of electric energy by wire is an example of particle transmission. Electrons move through the wire to supply energy to any point in a circuit. Heat energy is conducted through a metal bar by the collisions between molecules.

Waves can also carry energy from one place to another. The sound of the school bells, the light and heat from the sun reach us by means of waves. A cork moves up and down when the waves, generated by dropping a stone at the edge of a pond, arrive at the location of the cork. The energy imparted to the cork is brought by waves on the water surface. In wave motion, energy is transferred through the medium, although the particles of the medium are not transmitted. For example the sound of the school bell reaches us but the medium in between remains unaltered.

12.9. Kinds of Waves

Waves can be classified in terms of the way in which the motion of the individual particles of the medium is related to the movement of wave itself. The most common types of waves are transverse waves and longitudinal waves.

Transverse Waves:

The types of waves in which the vibrations of the individual particles of the medium are perpendicular to the direction of traveling wave are called transverse waves. They can be produced in strings, rods and other solid media For example, if the free end of a horizontal stretched cord is moved up and down in a simple harmonic manner then a train of transverse waves are produced that travel along the string. The particles of the cord vibrate locally in a simple harmonic manner with their displacement perpendicular to the propagation direction. Fig.(12.8)

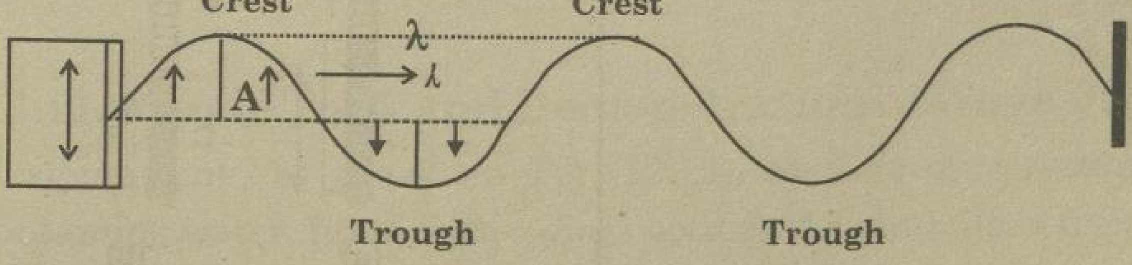


Fig.12.8. Propagation of transverse waves in a stretched string

When transverse waves pass through a medium, some of its particles move upward while some of them move downward. The part of the transverse waves where the particles of the medium are above the normal position is called *crest* and the part where the particles of the medium are below their normal position is called *trough*.

The distance between two consecutive crests or troughs is called wave length represented by λ. A crest and trough joins to make one complete wave. The number f waves passing through a fixed point in one second is the frequency of the waves. The amplitude of a particle of the medium of propagation is called the amplitude of the wave.

Longitudinal Waves

Waves in which the particles of the medium vibrate about their mean positions parallel to the direction of propagation of the waves are known as longitudinal or compressional waves.

Sound waves which, we shall study in the next chapter are an important example of longitudinal waves. See Fig. 12.9

Longitudinal waves begin to travel along a long helical spring which is fixed between two fixed supports, as shown in Fig. (12.9). Set into vibrations a few of the lower turns of the spring. Longitudinal waves are produced and can be observed to travel up along the spring.

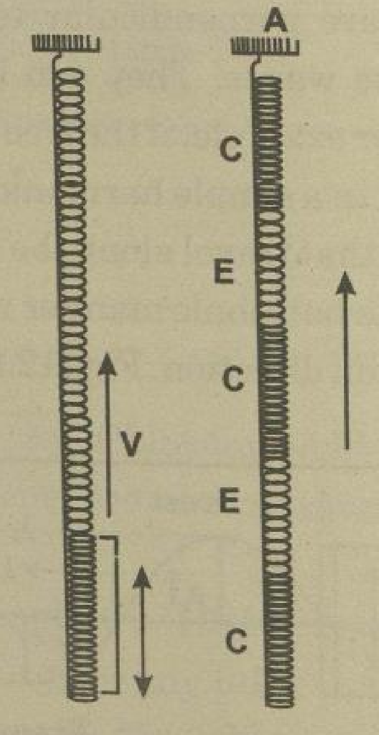


Fig. (12.9) Longitudinal wave in a spring.

12.10. Characteristic Wave Parameters

We have discussed the qualitative features of waves such as the generation, propagation and types of waves. We shall now study some of its quantitative characteristics such as the velocity, frequency, phase, wavelength amplitude and energy of waves.

Velocity of waves: The velocity of a wave is the distance traveled by it in unit time. Mathematically

$$v = \frac{s}{t}$$

The distance covered by a wave in one time period T is called wavelength λ. Hence the velocity, when expressed in terms of λ and T and the frequency f is given by:

$$v = \frac{\lambda}{T} \lambda f \qquad (12.9)$$

Velocity of a wave depends upon the nature of the waves, the physical properties of the medium of propagation such as the elasticity, density and temperature. Light and radio waves travel through air at about 3×10^8 ms^{-1}. Sound waves travel through air at about 330 ms^{-1} at 0°C.

Example 12.3. A radio station transmits news at frequency of 550 khz. Find the wavelength of the transmitted waves. The velocity of the radio waves is 3×10^8 ms^{-1}.

Solution:

Velocity of the waves = v = 3×10^8 ms^{-1}

Frequency of the waves = f = 550 khz = 550×10^3 s^{-1}

Wavelength of the waves = λ =?

$$\textbf{Since} \quad \lambda = \frac{v}{f} = \frac{3 \times 10^8 \text{ms}^{-1}}{550 \times 10^3 \text{s}^{-1}} = 5.45 \times 10^2 \text{m}.$$

12.11. Ripple Tank and Demonstration of Wave Properties

A ripple tank, as shown in Fig (12.10), consists of a rectangular tray containing water, fitted with a glass bottom. A light bulb is fixed above the tray and a viewing screen is placed well below the tray.

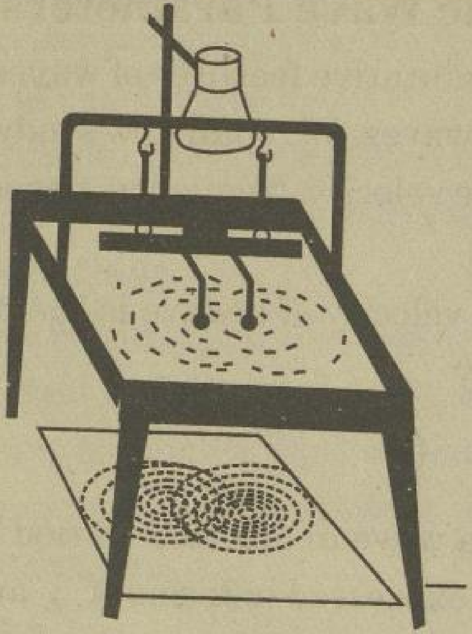


Fig.(12.10) Waves can be generated in a ripple tank.

Various types of waves can be produced in the tank by disturbing the water in different ways. A circular pulse can be produced by simply dipping finger into the water. Straight periodic waves can be generated by dipping a straight rod periodically into the water. This is done by means of a mechanical arrangement driven by a smallelectric motor. When waves are produced, the crests converge the light onto the screen to form bright bands while troughs diverge the light away from the screen and form dark bands. These bright and dark bands can be observed on the screen.

The most important properties of waves are reflection, refraction, diffraction and interference. These properties can be demonstrated by producing waves in the ripple tank.

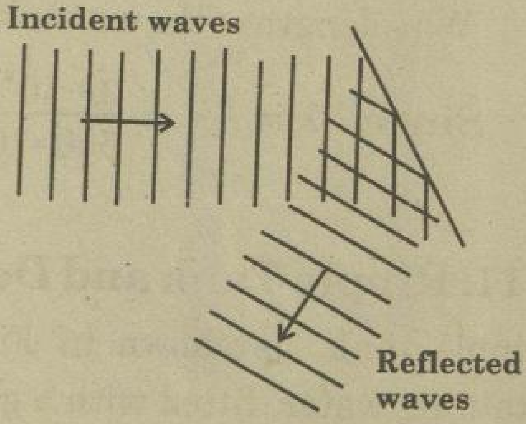


Fig.(12.11) Reflection of waves

Reflection of Waves:

Waves are reflected when an obstacle is placed in their path. In a ripple tank, reflection can be demonstrated by placing an upright surface in water.

Fig (12.11) shows reflection from a flat surface.

Refraction of Waves:

The speed of waves is different in different media. It is relatively greater in a "rarer" medium than in a denser medium. When waves enter from a rarer medium into a denser medium, they bend away slightly from their straight path. Such bending of waves is called refraction. This phenomenon can be demonstrated by the waves in a ripple tank. Place a plastic sheet in the bottom portion of the tray. Observe that the incident waves refract at the edge of the plastic sheet. In the present case, the speed of waves in the deeper water is greater than their speed in the shallower water.

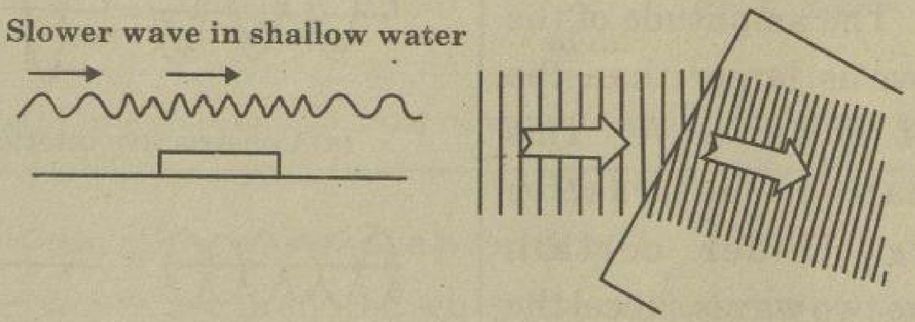


Fig.(12.12) Refraction of waves

The speed v of waves of frequency f and wave length λ is given by $v = \lambda f$. As v changes with the depth of water, so λ changes because f is an inherent constant for the waves. The speed as well as the wavelength of the waves is smaller in the shallower water.

Diffraction of Waves:

When waves pass through an opening whose size is somewhat smaller than the wavelength of the waves then the wave spread out in passing through the opening, Fig (12.13). This phenomenon is called diffraction. Waves also reach the geometrical shadow of the obstacle containing the opening. Diffraction of

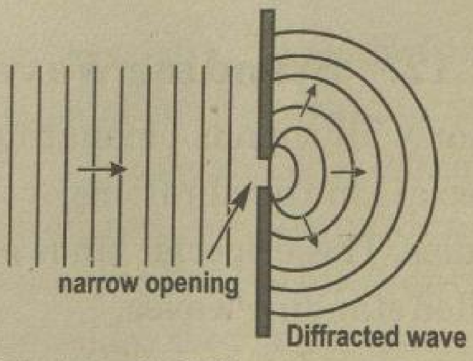


Fig.(12.13) Diffraction of waves

wave can be demonstrated by waves in a ripple tank.

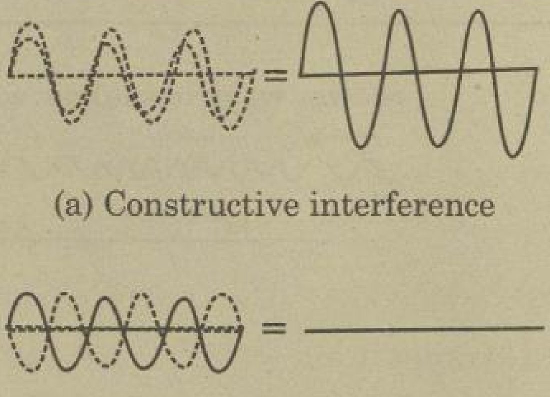
Bring two obstacles close together in a ripple take and leave a small opening between them. Generate waves in the ripple tank. You will observe that they diffract around the corners of the opening.

Interference of Waves:

When two wave pass simultaneously through thesame region then each wave sets each point of the region into vibrations. Inthis wave, one wave effects the vibrations caused by the other wave. The combined effect of two waves in the region of overlapping is called interference.

Under certain special conditions, one wave reinforces the other wave at each point. The amplitude of the resultant wave is larger than the amplitude of either wave. This effect is called *constructive interference*. Under certain conditions, the two waves cancel the effect of each other.

The resultant amplitude is zero for identical waves. This type of interference is called destructive interference.



(a) Constructive interference

(b) Destructive interference

Fig. (12.14)

The interference of wave can be demonstrated by means of wave generated in a ripple tank. Fix two identical balls with the rod of the vibrator, Fig. (12.15). The interference of waves as shown in the figure can be observed.

12.12. Standing Waves:

Nearly all sounds emanating from musical instruments are the result of special kind of vibrations of stretched strings, air columns or other vibrating bodies. These special kinds of vibrations, which will be discussed below, are called standing waves.

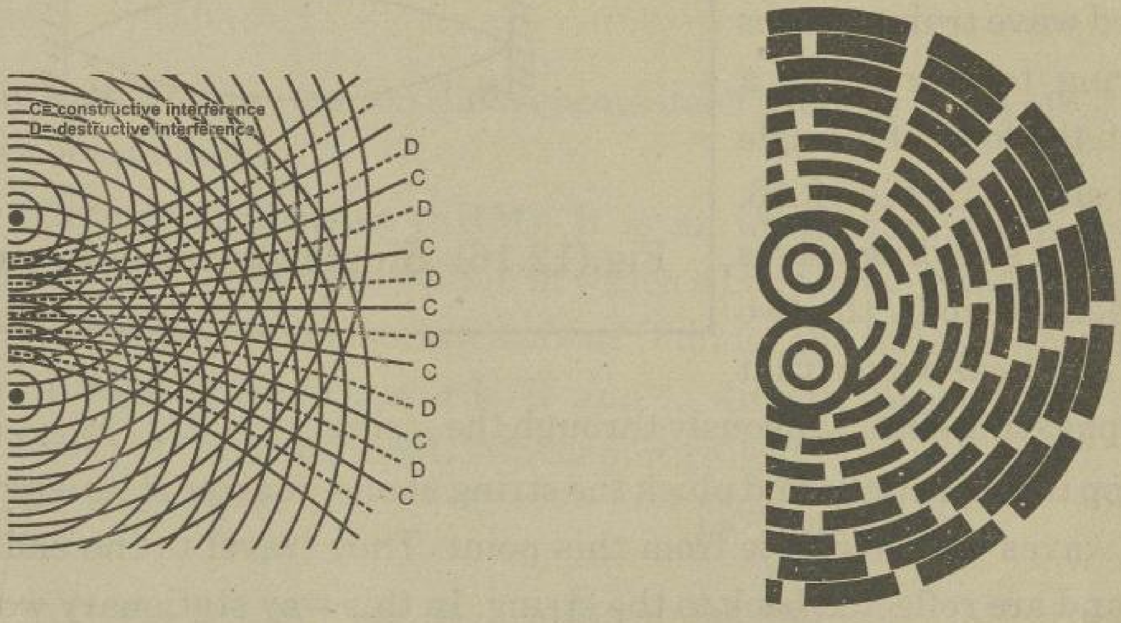


Fig.(12.15) Interference pattern of waves coming from two identical sources

How are standing waves are produced?

Standing waves are produced when two wave trains of the same frequency and amplitude and having proper phase relations travel in opposite directions through a medium. The two sets of travelling waves superimpose on each other at every point of the medium. Under special circumstances, and at particular places the travelling waves may interfere constructively or destructively. In this way, the medium of propagation is in a state of sustained vibrations, which are called standing waves.

At places of constructive interference, the amplitude of vibrations of the particles of the medium is large. At places of destructive interference, the amplitude is small.

Standing waves can be illustrated and understood by the vibrations of a stretched string. Take a steel string of length about 1m. Stretch it tightly and clamp it at its two ends. Pluck the string transversely at its mid-pint. Two sets of transverse waves will originate from this mid-point. One of them will move to the left end of the sting and the other will move towards the right end. When these waves reach the clamped ends, they are reflected back.

The incident and the reflected wave trains causes the string to vibrate as a whole in the form of a single loop as shown in Fig.12.16. We say that standing waves have been set up by the two sets of identical waves that are propagating simultaneously through the string.

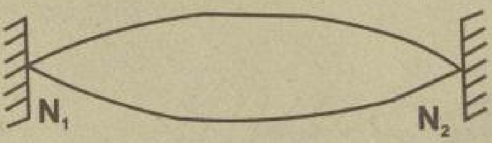


Fig.(12.16) .Single loop standing wave

Now stop the vibrations and pluck the string at one-quarter of its length. Two sets of waves will originate from this point. They travel to the ends of the string and are reflected back to the string. In this way stationary waves are set up. The string now vibrates in two loops as shown in Fig.(12.17).

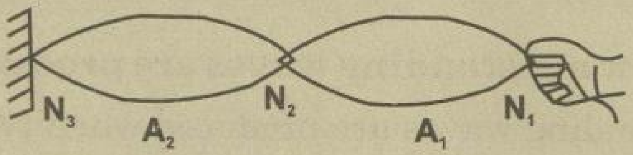


Fig.(12.17). Two loops standing wave

Now pluck the string at one-sixth of its length. It will oscillate in standing mode of three loops. There will be four nodes and three anti nodes. The wavelength λ_3 and the characteristic frequency f_3 are given by

$$\lambda_3 = \frac{21}{3}$$

$$f_3 = 3f_1 = \frac{2}{3}\sqrt{\frac{T}{ml}}$$

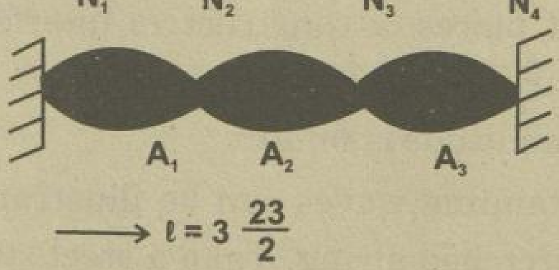


Fig. (12.18)

Now pluck the sting at any arbitrary point. This point can be specified by its length $\frac{1}{n}$ from the end point of the string, where n = 1,2,3 ----. The string will oscillate in its nth mode with (n+1) nodes and n antinodes. The wavelength λ_n and the frequency f_n in the nth mode are given by

$$\lambda_n = \frac{21}{n}$$

$$f_n = nf_1 = \frac{n}{2}\sqrt{\frac{T}{ml}}$$

SUMMARY

Periodic Motion: Any motion that repeats itself in equal intervals of time is called periodic motion.

Simple Harmonic Motion (SHM): It is an ideal vibratory motion. By definition SHM is that linear motion in which a body, once displaced from its equilibrium position O, so oscillates about O under the influence of a force F which is always directed towards O and is directly proportional to the displacement x of the body from O. Mathematically,

$$F = -kx \qquad [k = \text{constant}]$$

$$ma = -kx \Rightarrow a = -\frac{k}{m}x \quad (\text{as } F = ma)$$

Terminology: The terms used in describing a vibratory motion are: vibration; amplitude, time period and frequency. See text for their definitions.

Simple Pendulum: An ideal simple pendulum consists of a small and heavy metallic spherical bob which is suspended by a fine weightless and inextensible string from a fixed support. When the bob is slightly displaced from its equilibrium rest position, it starts oscillating about its equilibrium position. By analyzing the forces on the bob, it can be proved that the small oscillatory motion of the simple pendulum is simple harmonic. The time period 'T'of the simple pendulum of length **l** and bob of mass **m** is given by

$$T = 2\pi\sqrt{\frac{l}{g}}$$

Oscillation of a Mass Attached to a Spring: If a mass m attached to a spring whose one end fixed, is slightly stretched and then released it begins to oscillate in a SHM. The time period of the motion is given by

$$T = 2\pi\sqrt{\frac{m}{k}} \qquad (k = \text{constant of the spring})$$

Waves: A wave is a disturbance of some kind that propagates through a medium. An individual particle of the medium oscillates back and forth but it does not progress with the waves. Energy is transferred through the medium. Waves transport energy and not matter

Kinds of Waves: There are many kinds of waves. On the basis of the vibrations of the particles of the medium of propagation, waves can be classified into two kinds: Transverse waves and longitudinal waves.

Transverse Waves: The type of waves in which the vibrations of the individual particles of the medium are perpendicular to the direction, in which the wave travels, are called transverse waves. They can be produced in strings, rods and other solid media.

Longitudinal Waves: The type of waves in which the vibrations of the particles of the medium are parallel to the direction in which the wave travels, are called longitudinal waves. Sound waves are an example of longitudinal waves.

Waves as Energy Carriers: Energy can be carried from one place to another by means of waves. In this process the medium of propagation is vibrating. Energy is transported but not mass. On the basis of the medium of propagation, waves are of two types: Mechanical waves and electromagnetic waves. The former needs elastic material medium for their propagation whereas the latter can travel through a vacuum.

Quantitative Characteristic of Waves: Different waves can be specified quantitatively by their following parameters: velocity v, time period T, frequency f, amplitude A, wavelength λ and energy E. The details are given in the text.

Demonstration of the Properties of Waves by Ripple Tank: The main properties of waves are: Reflection; refraction; diffraction and interference. Each of these properties can be demonstrated by means of a ripple tank.

Standing Waves: Standing waves are produced when two wave trains of the same frequency and amplitude and having proper phase relations travel through a medium in opposite directions. The two sets of waves superimpose on each other at every point of the medium. Under special circumstances and at particular places the travelling waves may interfere constructively or destructively. In this way the medium of propagation is in a state of sustained vibrations, which are called standing waves. At places of constructive interference, the amplitude of the vibrations of the particle is large. These places are called antinodes. At places of destructive interference, the amplitude is almost zero. These places are called nodes. The particles of the medium can vibrate only in a set of characteristic frequencies. The lowest of these frequencies is called the fundamental frequency. The higher frequencies are integral multiples of the fundamental and are called harmonic frequencies.

EXERCISE

OBJECTIVE QUESTIONS

1. Encircle T for correct answer and F for false answer

i) Sound waves cannot pass through a vacuum T/F

ii) Light wave are mechanical waves T/F

iii) In a SH, the displacement is always opposite to the force. T/F

iv) The time period of a simple pendulum depends on the suspended mass. T/F

v) Electromagnetic waves can pass through a vacuum but cannot carry energy. T/F

2. Fill in the blanks in the following.

i) Sound waves are _______ waves while light waves are _______ waves.

ii) The energy of vibrating is sometimes entirely _______ and sometimes entirely _______.

iii) Every periodic motion can be decomposed into _______ motions.

iv) In a simple harmonic motion, the force is always directly proportional to ______ from the equilibrium position.

v) The time period of a simple pendulum depends on the following three factors:

(a) ______ (b) ______ (c) ______

vi) A disturbance in water travels in the form of ______

vii) In longitudinal waves, the vibrations of the particles of the medium are ______ to the direction of wave propagation

viii) One compression and rarefaction combine together to form a ______.

ix) The distance between two successive points of the same phase is called ______.

x) Wavelength, frequency and velocity of a wave are related by the equation ______.

xi) The quantitative characteristics of waves are:

(a) _____ (b) _____ (c) ______ (d) ______ (e) ______ (f) ______

SHORT ANSWER QUESTIONS

i) Write down the characteristics that are common to sound and light

ii) The lengths of two simple pendulums are the same. The bob of pendulum is four times heavier than that of the other. Compare the frequencies of the two pendulums

iii) The mass suspended from a vibrating string is increased four times. What is the effect on the time period and the frequency of oscillation of the mass-spring system?

iv) What are those two conditions that distinguish SHM from a to and fro periodic motion?

v) What are the two characteristics of a medium that are necessary for the propagation of mechanical waves?

vi) Distinguish between transverse waves and longitudinal waves.

vii) (a) What is the kinetic energy of a simple pendulum when the bob is at (i) Mean central position (ii) Extreme position

(b) What happens to the KE at the extreme position

COMPREHENSIVE QUESTIONS

1. Define periodic motion. Give three examples. Find the relation between the frequency and time period of a periodic motion.
2. Define simple harmonic motion (SHM). Describe its characteristic features giving two examples
3. What is a simple pendulum? Illustrate diagrammatically the forces acting on the bob of a simple pendulum. Prove that the component of the weight responsible for the vibration of the pendulum is always directed towards the equilibrium position.
4. Describe the characteristics of the motion of a simple pendulum.
5. Show that the vibrations of a mass suspended from a spring are simple harmonic. Describe the characteristic of this motion.
6. State Hooke's law. Illustrate this law with the example of an elastic spring.
7. Waves are produced on the surface of water by dropping a stone in a water tank. Explain the generation and propagation of these waves.
8. Define the terms: Wavelength, frequency, time period and amplitude of waves. Also derive the relation between the velocity, wavelength and frequency of waves:

$$v = \lambda f.$$

9. How will you produce continuously transverse simple harmonic waves in a stretched string? Explain the propagation of wave in the string.

10. Distinguish between transverse waves and longitudinal waves. Explain them with examples.

11. What is a wave? What are the characteristic features of a wave?

12. What is a ripple tank? What properties of waves can be demonstrated with the help of a ripple tank? Illustrate with diagrams.

13. What are the quantitative characteristics of a wave? Define and explain each characteristic.

14. What are the various modes of transportation of energy? Explain each mode with an example.

NUMERICAL PROBLEMS

1. A simple harmonic oscillator completes 10 vibrations in one second. Find the time period and frequency

[0.1 second, 10 hertz]

2. The frequency of a sound wave is 2.5 kHz. Find the time period.

[4×10^{-4} second]

3. The time period of a light wave is 1.6 10^{-15} second. Find the frequency.

[6.25×10^{14} Hz]

4. Waves pass through the surface of water. Pieces of paper move up and down and complete 40 oscillations in 4 seconds. The wavelength of the waves is 10 cm. Find the time period, frequency and velocity of the waves.

[0.1 second, 10 Hz, 1 ms^{-1}]

5. The length of a clock pendulum is 1 m. It gives correct time i.e. its time period is two seconds. Find the value of the acceleration due to gravity at the place of the clock.

6. A tiny pendulum is made from a quartz fiber. The length of the pendulum is 4m. Find the period and the frequency of the pendulum. **[0.128s, 7.8hertz]**

7. A mass of 125 gm is suspended from a light spring, the frequency of its simple harmonic vibrations is 2.6 hertz. If the mass is reduced to 50g and is suspended from the same spring, find its frequency.

[4.12hertz]

Chapter 13

SOUND

In this chapter you will study

- The nature of sound
- Generation, propagation and hearing of sound
- Sound waves: longitudinal waves as rise and fall of pressure in a medium
- Physical and musical characteristics of sound
- Distinction between normal sound and noise
- Forced and free vibrations; Resonance
- Resonance method of measuring the velocity of sound
- Audible frequency range of sound
- Ultrasonics and its applications

13.1 The Nature, Generation, Propagation and Hearing of Sound

Sound is a form of energy. It travels through a medium in the form of longitudinal waves. When sound falls on the ear-membrane, it produces the sensation of hearing. Three things are necessary for hearing sound:

vibrating body; ***transmitting medium*** and ***hearing receiver.***

Fig.(13.1) Stationary tuning fork and vibrating tuning fork

Generation of Sound

A vibrating body produces sound. As an activity, strike a metallic vessel with a spoon. The vessel gives out sound. Its vibrations can be felt by touching it gently with hand. Similarly, touch gently the ringing school bell. You will find that the bell vibrates.

In the school laboratory, a specific sound is produced by an instrument called tuning fork. A tuning fork, as shown in Fig.(13.1), has two prongs. Strike a tuning fork on a rubber pad. A specific sound is produced and the prongs of the fork are vibrating. You can feel the vibrations by touching the prongs.

Transmitting medium

The vibrating body supplies the energy of its vibrations to the surrounding medium. The transmitting medium transmits this energy from the source to the receiver by means of sound waves. The transmitting medium is usually air but sound can also travel through other media. The medium could be solid liquid or gas. A swimmer within a pond of water can hear the whistle of a referee. A boy in a lonely closed room can hear outside sounds. The reason is that sound waves can travel through air, solid walls, window pans and the ground. Sound cannot travel through vacuum. This statement can be demonstrated by the following experiment.

Suspend an electric bell in a jar by its wires through a cork fixed in its mouth as shown in Fig.(13.2). Switch on the bell. We hear the sound of the bell. Now

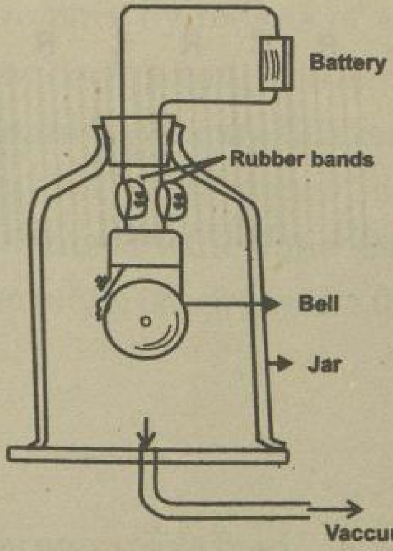


Fig.(13.2). Sound is not heard by removing air from the jar start removing air from the jar with the help of an exhaust pump. The sound of the bell gets weaker and weaker, until it can scarcely be heard, although the hammer is still seen striking the bell. If the air is readmitted into the jar, the sound will be heard again. There can be no sound in vacuum because there is nothing around the vibrating body through which the mechanical disturbance can travel to reach a person's ear.

The Hearing Device

Any device that can detect sound wave can be called as a hearing device. Ear is a device that converts sound waves into the sensation of hearing. Besides the natural ear, mechanical and electronic devices can be built to detect and analyze sound waves.

When sound waves fall on ear or a hearing device, the energy brought by the waves set the membrane of the ear into vibrations. The characteristics of the vibrations of the membrane are the same as that of the vibrating source.

13.2 Propagation of sound waves.

How does sound propagate through a medium?

Whenever a body vibrates, it produces a disturbance in the surrounding medium. The energy of vibrations of the body is transferred to the adjacent particles of the medium. These particles are set into vibrations. In turn,

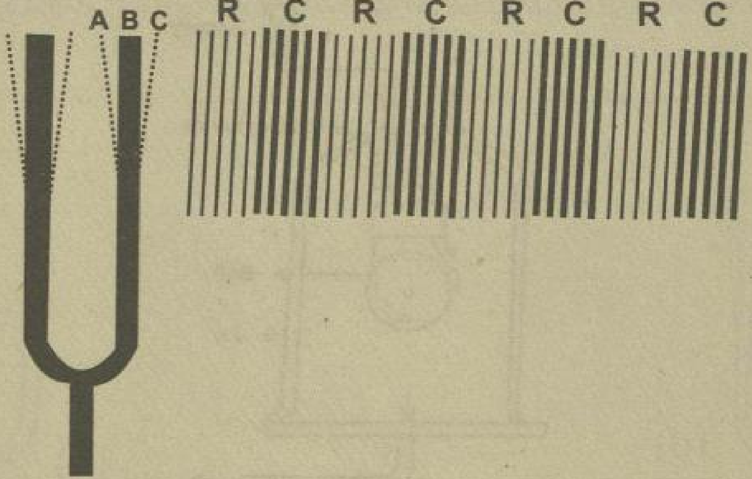


Fig.(13.3) Sound waves propagating in air these particles transfer some energy to the neighboring particles and set them into vibrations. In this way, the energy of vibrations propagates through the medium from the source to the receiving end.

Sound waves in air are longitudinal waves of the rise and fall in the pressure of air in the atmosphere. The longitudinal waves produced by a vibrating tuning fork are shown propagating through air in Fig. (13.3). When the right prong of the vibrating fork moves from position A to C, it compresses the layer of air next to it. This layer of air, in turn, compresses the layer beyond it and so on. The compression that is started by the rightward movement of the prong travels out in the surrounding air. A moment later the prong begins to move from C to A, leaving a layer of decreased air pressure in its wake, i.e. the adjacent layer of air is rarefied. As in the case of compression, the rarefaction thus produced also travels out through the air from the vibrating fork. As the fork vibrates continuously, a regular succession of compressions and rarefactions travels out from the source. Such a series of alternate compressions and rarefactions constitute a wave motion. The compression and the following rarefaction make up a compressional wave. When compressional waves reach the ear of a nearby observer, they cause the sensation of hearing and are referred to as sound waves.

13.3 Characteristics of Sound

Man has been gifted with two ears by means of which, he can distinguish among numerous kinds of sounds. We can distinguish among Azan, speech, music and honking horns. Similarly, we can differentiate among the voices of children, men and women. In fact, there are a few fundamental characteristics of sound by means of which one sound can be distinguished from another sound. These characteristics are the following.

i. Loudness
ii. Pitch
iii. Quality

Each of these characteristics is now explained

Intensity and Loudness

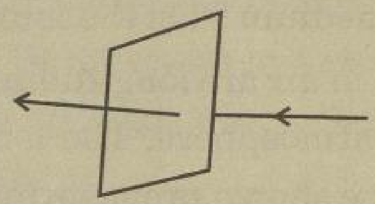


Fig.(13.4). Illustration of the intensity of sound

Intensity of sound waves is defined as the energy carried by sound waves per unit time through a unit area placed perpendicular to the direction of the waves. See Fig. (13.4). If the intensity is low, the sound can hardly be heard. If the intensity is very high, it produces pain in the ear.

The intensity of sound and consequently its loudness depends on the following characteristics of vibrating sources of sound as well as on the state of the transmitting medium between the source and the listener.

i. The amplitude of the vibrating object
ii. The frequency of vibrating object
iii. Surface area of the vibrating object
iv. The distance of the listener from the vibrating object
v. The direction of wind

In general an increase in the amplitude, frequency or the surface area of the vibrating object causes an increase in the intensity and the loudness of the emitted sound waves. A drum produces loud sound when its membrane is struck strongly whereas the sound is faint when the membrane is struck gently. This shows that greater the amplitude of a vibrating body the louder is the sound. A drum (dhool) produces a louder sound compared with that produced by a dhoolac (a smaller drum). It can also be observed that the sound produced by a thin taut membrane of a drum produces louder sound than that produced by a thick loose membrane of a drum. The reason is that the frequency, in the former case, is higher than in the later case.

The loudness of a sound increases or decreases as the distance between the source of sound and the listener decreases or increases respectively. To avoid

Table 13.1

Sound	Intensity Wm^{-2}	Level of Sound in db
Loudest sound: Stereo, painful	1	120
Rattling of train	10^{-2}	100
Heavy traffic	10^{-3}	90
Common talk	10^{-6}	60
Whispering	10^{-10}	20
Rustling of leaves	10^{-11}	10
Faintest sound	10^{-12}	0

the uncomfortable loud sound, we move away from a drum being beaten violently. We also experience that a sound is heard to be louder if it travels in the same direction in which the wind blows. It seems to be faint if it travels in the opposite direction.

The intensity of sound and consequently the loudness of sound are expressed in units of decibels. The intensity of a few sounds, on the decibel scale, is given in Table (13.1). The meaning of sound, of intensity I and n-db is obvious from the following definition

$$n \text{ db} = 10 \log \frac{I}{I_o} \qquad (13.1)$$

where I_o is a reference intensity and is commonly chosen as 10^{-12} watt m^{-2} which corresponds to the intensity of the faintest possible sound. A 60 db sound means:

$$60 = 10 \log \frac{I}{I_o}$$

$$\Rightarrow \log \frac{I}{I_o} = \frac{60}{10} = 6 \Rightarrow \frac{I}{I_o} = 10^6$$

$$\Rightarrow I = 10^6 I_o$$

Pitch of a Sound

The pitch of a sound is a characteristic of sound by means of which a shrill sound can be distinguished from a flat sound. The sounds produced by birds, cats, children and women are of high pitch whereas the sounds by dogs, frogs, and men etc are of low pitch. In general, the pitch of a sound depends on the frequency of the sound. The greater the frequency, the higher is the pitch and shriller is the sound. This can be demonstrated by an activity described below.

Rotate the wheel of a bicycle. Take a piece of cardboard and hold it so close to the wheel that it touches the needle bars. A sound is produced. As the wheel is rotated faster and faster, the frequency of vibrations of the piece of cardboard increases. The shrill, that is, the pitch of the sound increases.

The Quality of Sound

The property of sound by virtue of which it is possible to identify a sound of the same loudness and same pitch but originating from different instruments is called quality or timber. You can easily distinguish among the sounds produced by violins, flutes, sitars and pianos being played simultaneously in a hall. The quality property of sounds can be easily understood from physical point of view.

Fig. (13.5) shows the same note played by piano and clarinet at the same loudness. The waveform of clarinet sound is complex, rich in harmonics and is of higher quality than that of piano.

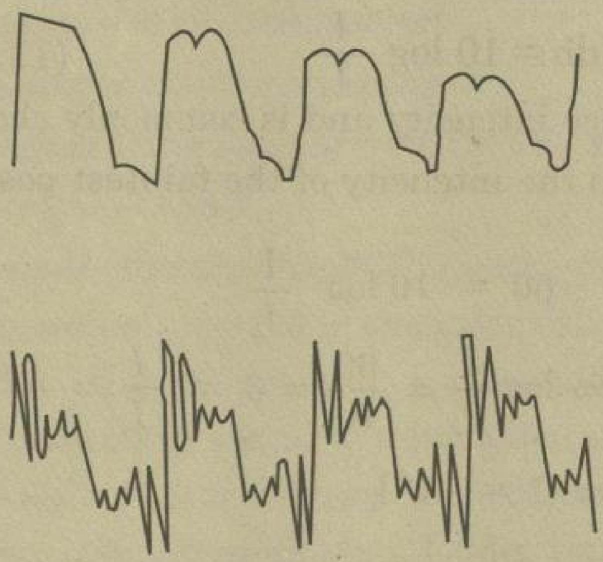


Fig (13.5). The quality of sounds from piano and clarinet is different even if their pitch and loudness is same

13.4 Musical Sound and Noise

The sound produced by playing on harmonium, flute or sitar etc produces a pleasing sensation in the ear. Such sounds are called musical sounds. They are sounds that occur in quick succession at regular intervals without sudden changes in loudness.

On the contrary, the rattling of vehicles, the honking of pressure horns, the sound of a powerful drill machine and erratic playing of a tap recorder produce a displeasing effect in the year. Such sounds are called noise. Noisy sounds are of very short duration having no periodicity and no definite amplitude. The changes in loudness are sharp and erratic. The irregular sharp changes in noisy sounds cause similar vibrations of the ear-drum. These vibrations are irritating and jarring.

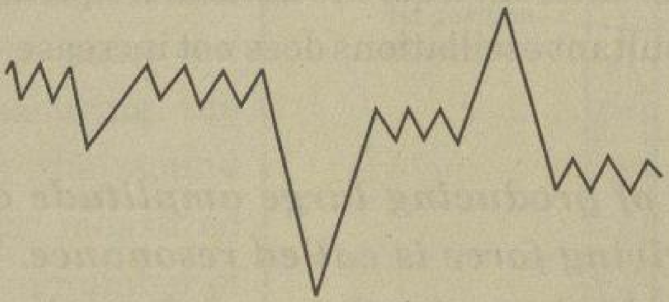


Fig.(13.6) Sudden and erratic change in waves of noise.

13.5 Free and Forced Vibrations, Resonance

Free Vibration

You know that the frequency of oscillation of a simple pendulum of length l is given by

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{g}{l}} \qquad (13.2)$$

Whenever this pendulum is disturbed, it will oscillated with the same frequency f_0 and not with any other frequency. The frequency f_0 is called the natural frequency of oscillation of the pendulum.

Let this pendulum be acted upon by an external periodic force of frequency f. It is found by experiment that when $f = f_0$, then the pendulum is thrown into natural vibrations of large amplitude even by a small external periodic force. The effect is general and not limited only to a simple pendulum.

Forced Vibrations

We would like to know as to what is the effect of an external force on a body executing vibration with its natural frequency.

Make a second's pendulum and let it rest in equilibrium position. Now apply to it an external periodic force of frequency different than the natural frequency of the pendulum. For example push it leftward, after every 1.5s. You will observe that the amplitude of the pendulum does not increase. The pendulum no longer oscillates with its natural frequency. Vibrations under an external force are called force vibrations. In general, when the frequency of an external force is different from the natural frequency of an oscillator the amplitude of the resultant oscillations does not increase.

Resonance:

The phenomenon of producing large amplitude of oscillation by a small periodic driving force is called resonance. The phenomenon of resonance can be used to determine the speed of sound in air.

Examples of Resonance:

(i) **Swing**: A swing has a natural frequency of oscillations. Its amplitude increases if a periodic force is applied whose frequency is equal to the natural frequency of oscillation of the swing.

(ii) **Suspension bridge**: A suspension bridge has a natural frequency of oscillation. A column of soldiers marching on the bridge is ordered to break their regular steps. The reason is that if the frequency of the steps equals the frequency of oscillation of the bridge, then the bridge may be thrown into resonance with large amplitude. The bridge may collapse. To avoid such collapse, the steps are made random.

(iii) Hearing of sound by means of a radio is another example of resonance. When the frequency of the tuning circuit of the radio equals the frequency of waves transmitted by a radio station, then sound is produced by the radio.

13.6 Velocity of Sound

It is a common observation that the thunder of lightening is heard relatively later than flash of light. Similarly the report of a distant gun-fire is heard later than the flash of light. The reason is that sound travels much slower than light.

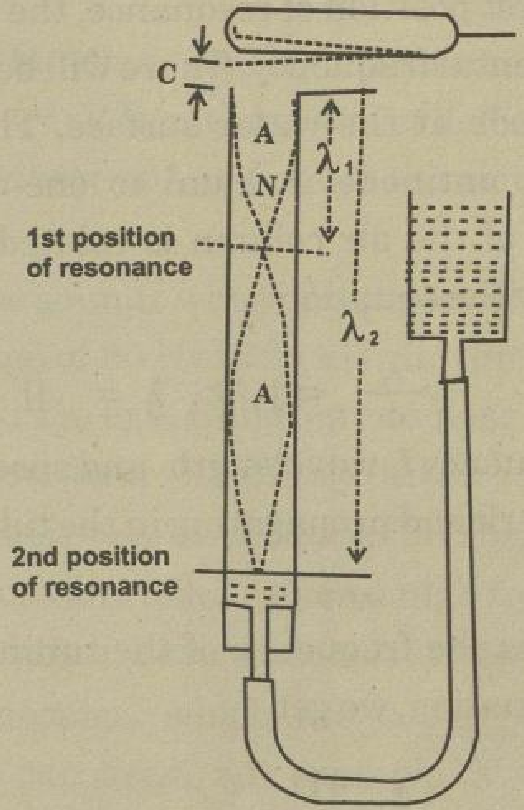


Fig. (13.7). Measurement of the speed of sound in air by resonance method.

The speed of sound in a given medium is defined as the distance covered by sound in unit time. It varies greatly with material medium through which sound travels. It may be determined by measuring the time required for the sound waves to travel a measured distance. There are a number of methods of measuring the speed of sound. One of them is given as under.

Fig. (13.7) shows a column of air, which is enclosed by a vertical glass tube. The tube is connected to a water reservoir. Moving the reservoir up or down can change the length of the air column. The air column, when disturbed, can vibrate in its natural fundamental frequency as well as its harmonic frequencies. Besides other factors, the frequencies of natural oscillations depend upon the length of air column. Changing the length of the air column changes the set of natural frequencies of oscillations.

Hold a vibrating tuning fork horizontally over the open end of the glass tube. The tuning fork forces the air column in the tube to vibrate. Starting from a small length of the air column, increase its length gradually. For a certain the air column resonates with the frequency of the tuning fork. In other words, the tuning fork and the air column vibrate with the same frequency.

The phenomenon of resonance occurs as follows. When the tuning fork vibrates near the edge of the tube, it starts sending compressional waves. These waves are reflected by striking the water surface. The reflected waves and the incoming waves produce standing waves in a state of resonance.

In the first position of resonance, the air column in the tube vibrates with its fundamental frequency. There will be an antinode at the open end of the tube and a node at the water surface. The distance between the node and the adjacent antinode is equal to one-quarter of wavelength. Therefore the length l of the air column is related to the wavelength of the stationary waves by the equation

$$\frac{\lambda}{4} = l \Rightarrow \lambda = 4l \qquad (13.3)$$

The frequency f, wavelength and speed v of the sound waves produced by the tuning fork and propagating in the tube are related by the equation

$$v = f\lambda$$

where f is the frequency of the tuning fork. Substitute the value of in the above equation, we get

$$v = 4fl \qquad (13.4)$$

Since we know the values of f and l, the speed of sound in air can be calculated.

The speed of sound in air is 330 ms^{-1}. Its speed in water is 1450 ms^{-1}, and in iron, it is 5130 ms^{-1}. The speed of sound in any medium depends on the elasticity s well as the density of the medium. The speed increases with elasticity and decreases with density of the medium. The speed of sound in air increases with increase in the temperature of air.

Example 13.1. The thunder of clouds is heard 5 seconds after the lightning. Find out how distant are the clouds. Take the speed of sound as 340 ms^{-1}.

Solution:

Speed of sound $= v = 340\,ms^{-1}$

Time taken by sound to reach the listener $= t = 5\,s$.

Distance of the clouds $= d = ?$

$$d = vt = 340\,ms^{-1}\;5\,s = 1700\,m = 1.7\,km$$

13.7 Audible Frequency Range

We know that a sounding body must be vibrating. Its vibrations produce sound waves in the surrounding medium. When these waves fall upon our ears, they set the ear-membrane into vibrations and cause the sensation of sound.

A typical human ear can hear only those sounds whose frequency is between 20 Hz and 20,000 Hz. This audible range of 20 Hz to 20 kHz is different for different persons and it also varies with the age. Children can hear sound of 20 kHz while elderly people cannot hear anything above 15 kHz. A sound of frequency greater than 20 kHz can be produced but human ear cannot detect it because eardrum cannot vibrate with such a high frequency. Sounds having frequency more than 20 kHz are known as ultrasonics.

In contrast to ultrasonics are infrasonics, which are sound waves of frequency lower than the human ear can hear. For example, a vibrating simple pendulum does not produce an audible sound. Its frequency is too low to be heard.

13.8 Ultrasonics

The human ear can not hear sounds of frequency lower than 20 hertz and higher than about 20,000 hertz. Longitudinal waves of frequency more than 20 kHz are called ultrasonics. Such waves are usually produced by setting a quartz crystal to oscillate electrically

Generation and Applications of Ultrsonics

It is possible to produce ultrasonic waves of frequencies of the order of 10^9 Hz. They carry energy and the intensity I of the waves of frequency f, amplitude A and velocity 'v' is given by

$$I = 2\pi^2 f^2 A^2 v\rho \qquad (13.6)$$

where ρ is the density of the transmitting medium.

Because of their high frequency, ultrasonic waves are very powerful as compared with audible sound waves of the same amplitude. Ultrasonics are practically used in medical, scientific and industrial fields. A few of its application are described below.

Breaking of Kidney Stones

From food, stones are formed in the kidneys of some persons. Because of this, the patients feel a severe pain. High power ultrasonic machines are used in hospitals to break the kidney stones. Ultrasonic waves are focused on the stones in the kidney. The high power beam breaks the stone into small pieces. The pieces excreted through the urinal track. The patients need not an operation. The ultrasonic treatment is safer and more effective than x-rays or operation.

Checking of an unborn baby in the womb of an expecting mother can be done with ultrasonics. An ultrasonic transmitter is moved over the mother's body. A detector picks up ultrasonic waves reflected from different layers inside the body. The signals are processed by a computer, which puts an image on a screen. The method is safer than x-rays because x-rays damage body cells.

Quality Control

Ultrasonics are used in mills making iron, copper or aluminum sheets. The uniformity of thickness of the metallic sheets is automatically controlled by an ultrasonic detector. Fig. (13.8) shows an ultrasonic detector that controls the gap between two rollers. Its job is to make sure that the steel

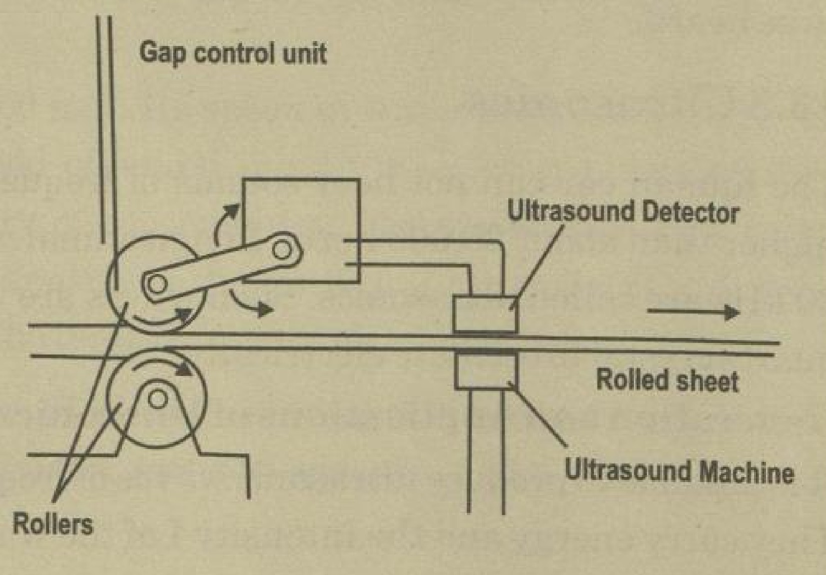


Fig.(13.8). Material testing

is not rolled too thickly or too thinly

Material Testing

Fault free, high quality materials are essentially required for making space crafts, aeroplanes, high speed machines and other strong structures. There should be no cracks, internal holes or hollows in high quality materials. Such faults are normally not visible but they can be very dangerous. Such crack and cavities can be detected by ultrasonics. A powerful beam of ultrasonics is made to pass through a material. While passing, these waves are reflected by the surface of the cracks and hollows. The comparison of the ultrasonic waves reflected from the cracks and from the other non-faulty surfaces can give a clue of the existence of faults.

Ultrasound Cleaning

Using ultrasonics, delicate machinery and instruments can be cleaned without dismantling. The machinery is immersed in a tank of liquid. High power vibrations of ultrasound are used which remove the bits of dirt and grease. Ultrasound cleaners are especially popular with jewellers and material scientists for cleaning their instruments. Ultrasonic waves are used for the scaling of teeth. Their vibrations remove the dirt and plaque sticking to the teeth.

Sonar

Sonar is the abbreviation of “sound navigation and ranging”. It is an apparatus that transmits high-frequency sound waves and registers the echo of its waves which are reflected back from a distant object. Sonar is similar to Radar but it uses sound waves instead of radio waves.

The sound waves transmitted by sonar can travel through the salty sea water. The electromagnetic microwaves sent out by radar are absorbed by sea water and cannot propagate through it. Using sonar, submarines submerged in seas can be detected. Sonar waves can be utilized to locate schools of fish in the sea.

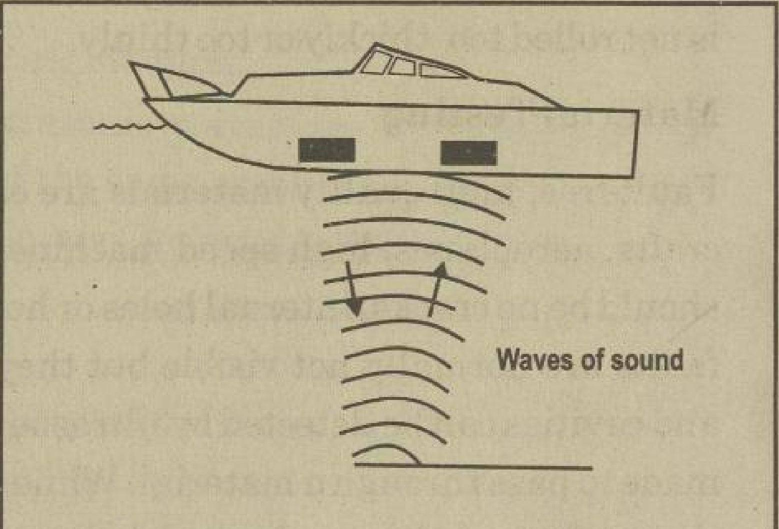


Fig.(13.9). Finding depth of ocean by sonar

The depth of an ocean can be determined by using ultrasonics. An ultrasonic pulse is sent down towards the ocean bed from the bottom of a ship. This pulse after reflection from the ocean bed, reaches the ship where it is detected. The time t taken by the ultrasonic pulse in travelling from the ship to the ocean bed and back to the ship is measured. The speed v of sound in sea water is 1450 ms^{-1}. The depth of ocean at the location of the ship can be determined:

$$\text{Depth of ocean} = vt \qquad (13.7)$$

SUMMARY

Sound is an agent of carrying energy and produces the sensation of hearing. Three things are necessary for hearing sound: a vibrating body; a transmitting material medium and a hearing device.

Every vibrating object sends out sound waves through a transmitting medium. The human ear can hear sounds within the audible frequency range of 20 Hz to 20,000 Hz. Sound travels through a given medium with a specific speed. Its speed in air is 330 ms^{-1} and speed in water is 1450 $m\ s^{-1}$. The speed of sound in a medium depends on the elasticity and the density of the medium. The speed increases with increase in elasticity but decreases with increase in density of the medium.

Sound has three fundamental characteristics by means of which one sound can be distinguished from another sound. These characteristics are: the intensity, frequency and waveform. A common listener call them loudness, pitch and quality respectively.

Sounds, which produce pleasing effect, are called musical sounds. Such sounds have definite frequency, amplitude and wave shape. On the contrary, sounds, which produce displeasing effect are called noise. Noisy sounds are erratic and have no definite frequency or amplitude. Sounds whose frequency is greater than 20 kHz are called ultrasonics and have many practical applications.

Each vibrating body has a natural frequency of oscillation. An external periodic force can be applied to it. When an external periodic force of frequency equal to the natural frequency of oscillation of a body is applied, the amplitude of oscillation increases. This phenomenon is called resonance.

1. OBJECTIVE QUESTIONS

Fill in the blanks.

i. When a body vibrates, _______ is produced

ii. Three things are necessary for the hearing of sound

(a)_______ (b) _______ (c) _______.

Sound wave travel in air in a succession of_______ and _______.

iv. Sound wave supply_______ to the ear-drum. Then the ear-drum _______.

v. In resonance, the_________ of a vibrating body and the _______ of the external periodic force are equal.

vi. The frequency of audible sound is between _______ Hz and _______ Hz.

vii. The loudness of a sound increases by increasing the following features of the vibrating body:

(a)_______ (b)_______ (c) _______

viii. A women's voice is of higher _______ than a man's voice.

ix. If a vibrating body has large surface area then it produces a _______ sound.

ix. The quality of a sound depends on the _______.

x. Different sounds can be distinguished by their following characteristics:

(a) _______ (b) _______ (c) _______

xii. Every complex vibration is composed of a number _____ vibrations.

2. SHORT ANSWER QUESTIONS

i. Why are ultrasonic waves not audible?

ii. Why the waves produced by a simple pendulum not heard?

iii. What is meant by the natural frequency of an oscillator?

iv. What is the fundamental condition for resonance?

v. Why does the school bell produce a loud sound.?

vi. Why is the sound produced by a 'dhool' louder than that of a 'dhoolac'?

vii. What could be the difference between the ear structures of a deaf person and a normal person?

viii. Explain, why the arrival of a train can be judged earlier and more distinctly by placing your ear on there railway line as compared with the normal method.

3. COMPREHENSIVE QUESTIONS

1. Discuss the generation, propagation and the receiving of sound waves.
2. Give the principle, construction, working and the result of measuring the speed of sound in air
3. Define the intensity as well as the loudness of sound. On what factors do they depend upon?
4. Define the terms pitch and quality of sound. Explain each term by giving examples.

5. Write a note on resonance.

6. What are ultrasonics? Describe three different applications of ultrasonics.

4. NUMERICAL PROBLEMS

1. The speed of sound at the ambient temperature of 15°C is 340 ms^{-1}. Find the speed in kilometer per hour.

2. Find the minimum as well us the maximum wavelength of audible sounds. The speed of sound is 330 m s^{-1}. **[1.6 cm, 16.5m]**

3. The thunder sound of lightening in clouds reaches 8 seconds later than the flash of light. How far will be the clouds? The speed of sound is 340 m s^{-1}. **[2.72 km]**

4. A hunter fires at a prey with a gun. The prey is hit and falls down. Five seconds later, the hunter hears the sound of the gunfire which is reflected from a hill. How far is the hill from the hunter? **[856 m]**

5. The wavelength of a musical note in air is 10 cm. The velocity of sound in air is 340 m s^{-1}. Find the frequency of the musical note. **[3400 Hz]**

6. An instrument used for measurement the depth of oceans sends ultrasonic signals to the bottom of the ocean. The signal is received in 0.75 seconds after reflection from the bottom of the ocean. The frequency of the signal is 60 kHz and the velocity of the ultrasonic signals in seawater is 1450 m s^{-1}. Find the depth of the ocean at the location of the experiment. **[544 m]**

7. A vibrating tuning fork of frequency 256 Hz is held over the top of a vertical tube full of water. The water is allowed to flow out slowly from the tube. A loud sound is heard when the air column in the tube is 33 cm. Calculate the speed of sound in air. **[338ms^{-1}]**

Chapter 14 A

REFLECTION OF LIGHT

In this chapter you will study

- Reflection and Laws of reflection of light
- Spherical mirrors
- Formation of Image in spherical mirrors
- Derivation of spherical mirror formula for images
- Magnification of image
- Uses of mirrors

14 A .1 Introduction

The reddish rising sun, the blue sky, the snow-clad whitish mountains and the variously coloured flowers around us remind us the beauty of nature. All these scenes are observed by dint of light. Without light, there would be absolute darkness. The beautiful objects around are seen when light coming from these objects enters our eyes.

What is light? What are its properties? Light is a form of energy. It travels in the form of waves in transparent media as well as in vacuum with very high speed. Light exhibits the properties of reflection, refraction, diffraction and interference. In this chapter we will study the propagation and reflection of light

14A.2 Reflection of Light

In a homogenous medium such as air, a beam of light travels in a straight line. However, when it falls on the boundary of another medium then a part of it bounces back from there. This is known as reflection of light. The amount of light reflected from the boundary or the surface of other medium depends on the nature and smoothness of that surface. From a highly polished surface nearly all light is reflected. But if the other medium is transparent, then some light will be transmitted into that medium. ***The smooth and polished surfaces of a medium from where most of light is reflected are called mirrors.***

In a study of reflection of light, a few terms need to be defined.

Fig. (14A.1) shows a ray CP striking the common interface MM′ of air and glass. The point P is called the point of incidence. The ray CP is called incident ray. The ray PB is called reflected ray and the ray PA is called is called refracted ray. At point P and perpendicular to MM′, the normal NPN′ is termed as normal. The angle i = CN, between the incident ray and the normal is called the angle of incidence. The angle r = BN, between the reflected ray and the normal is called the angle of reflection.

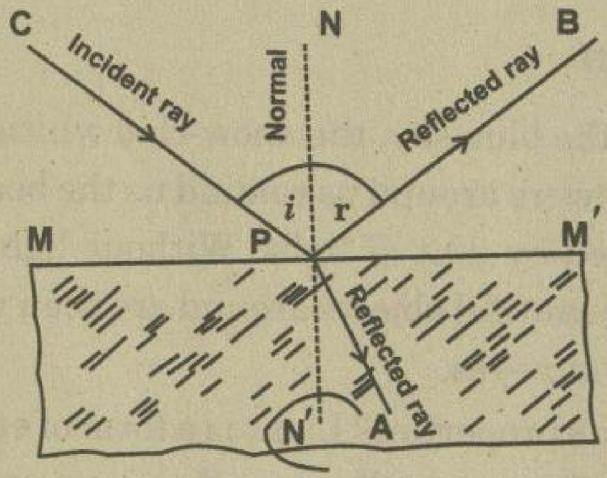


Fig. (14A.1) Reflection of light from the common surface of air and glass

14A.3 Laws of Reflection of Light

There are two laws of reflection of light. They were first discovered by the Muslim scientist Ibnal-Haitham. Consider Fig.(14A.1). MM′ is a plane surface. A luminous point C is located in front of MM′. Rays of lighted are radiating from C in all directions. In Fig.(14A.1), a single ray CP is shown as incident ray which is reflected as ray PB. The laws of reflection are as follows

(i) The angle of incidence $\hat{i}$ is equal to the angle of reflection $\hat{r}$.

(ii) The incident ray, the reflected ray and the normal to the interface at the point of incidence all lie in the same plane, which is called the plane of incidence.

14A.4 Spherical Mirrors

A hollow spherical object is called spherical shell. A section of a spherical shell with its inner or outer surface polished to reflect light is called a spherical mirror. Spherical mirrors are of two types: Concave mirror and convex mirror. The shining surface of a concave mirror curves inwards, whereas the shining surface of a convex mirror bulges outward. Fig. (14A.2a) shows a concave mirror and Fig.(14A.2b) shows a convex mirror. Each of them is a part of a spherical shell.

Definition of Special Terms

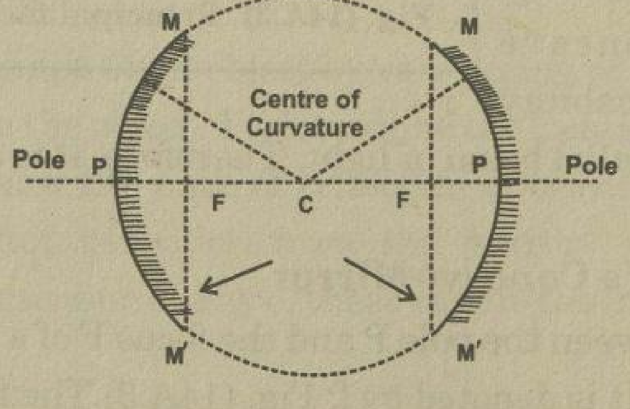
The special terms used in describing images formed by spherical mirror are given below.

Centre of Curvature

The centre of the hollow sphere of which the mirror is a part is called the centre of curvature of the spherical mirror, Fig. (14A.2a)

Radius of Curvature:

The radius of the sphere of which the mirror is a part is called the radius of curvature of that mirror, Fig. (14A.2b)



Convex Mirror and Concave mirror

Fig. (14A. 2) **(a)** **(b)**

Pole

The geometric central point of the spherical mirror is called its pole. It is labeled by P in the figure.

Aperture

Usually a spherical mirror has a circular boundary. The diameter of this circular boundary is called the aperture of the mirror. If a small portion of a spherical mirror is exposed to light, then the diameter of the exposed portion is called its aperture.

Principal Axis

The straight line passing through the pole P and the centre of curvature C is called the principal axis of that mirror.

Principal Focus of a Concave Mirror

When rays of light, parallel to the principal axis, fall on a concave mirror, they converge at a point on the principal axis after reflection from the mirror. This point is called the focus of the concave mirror. It is denoted by F in Fig. (14A.3). A concave mirror has the capability to converge a parallel beam of light. Therefore, it is also called a converging mirror.

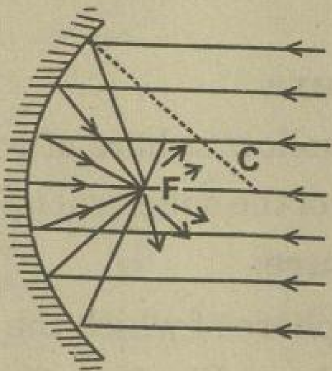


Fig. (14A.3). Principal focus of a concave mirror

Focal Length of a Concave Mirror

The distance between the pole P and the focus F of a concave mirror is called the focal length. It is denoted by f, Fig. (14A.3).The focal length of a concave mirror is considered positive. The focal length of a concave mirror is equal to one -half of the radius of curvature R, that is, $f = \frac{1}{2} R$.

Focus of a Convex Mirror

When rays of light, parallel to the principal axis, fall on a convex mirror, they diverge after reflection from the convex mirror, in such a way, that they appear to come from a point on the principal axis behind the mirror. This point is called the focus F of the convex mirror, Fig. (14A.4). This type of mirror has the ability to diverge a parallel beam of incident beam. Therefore, it is also called a diverging mirror.

Focal Length of a Convex Mirror.

The distance between the pole and the focus of the convex mirror is called the focal length f of the mirror. The focal length of a convex mirror is considered negative.

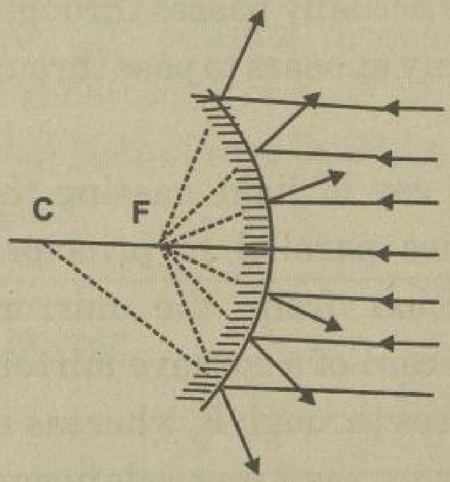


Fig.(14A.4). Focal length of a convex mirror

Reflection of Special Rays

A spherical mirror forms image of an object by converging or diverging the numerous rays coming from the object. To determine the location and nature of the image we need to know the path of reflection of only four rays. The direction of these rays after reflection from the mirror can be easily predicted. The point of intersection of any of these rays is the image point I of the object point O.

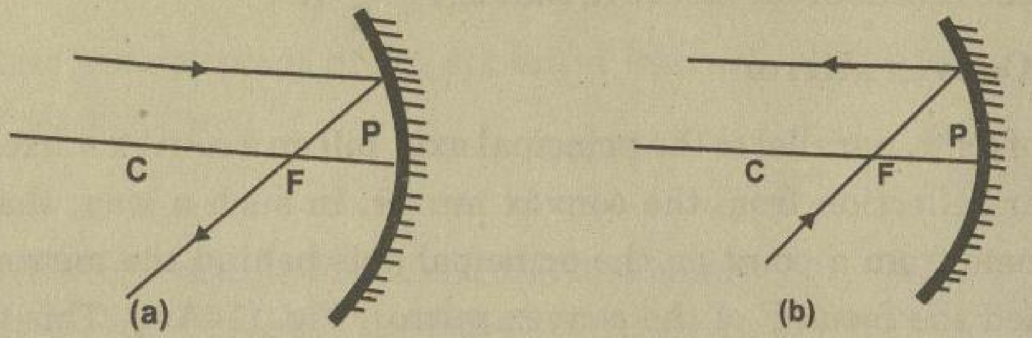


Fig. (14A.5A) Reflection of the special rays

Ray 1: The ray of light parallel to the principal axis passes through the focus after reflection from the spherical mirror. In case of the concave mirror, the reflected ray actually passes through the focus. In case of the convex mirror this special ray appears to pass through the focus. See Fig.(14A.5).

Ray 2: The ray of light passing through focus becomes parallel to principal axis after reflection from the mirror Fig. (14A.5A). In case of a concave mirror, ray2 actually passes through F, whereas in case of convex mirror, ray 2 proceeds towards F.

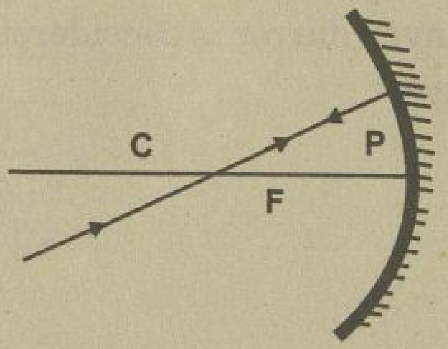


Fig. (14A. 5B)

Ray 3: The ray of light passing through the centre of curvature C or proceeding towards C of a spherical mirror is reflected back along the same path.

Ray 4: A ray incident on the pole at an angle with the principal axis is reflected back at the same angle.

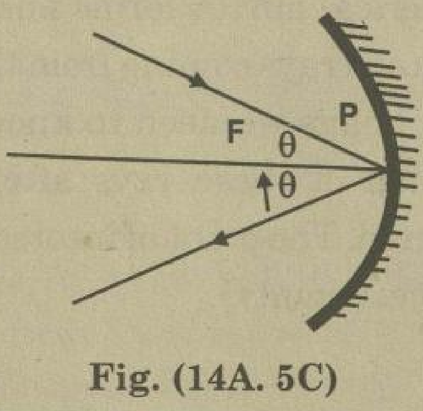


Fig. (14A. 5C)

14A.5. Image Formation By Concave Mirror

The position, size and the nature of the image of an object placed in front of a concave mirror depends on the location of the object with respect to the mirror. Starting from the case of a distant object, we consider the formation of images when the object is gradually brought very close to the concave mirror.

(i) Distant Object (Beyond C)

Let an object AB be placed at the principal axis of a concave mirror at a place beyond the centre of curvature C of the mirror, Fig. (14A.6). A number of rays emanate from the point A of the object. We consider only two rays. The ray AD is parallel to the principal axis. This ray will pass through F after reflection from the mirror. Another ray AC passing through C will be reflected back along its path. The two reflected rays meet at the point A' which is the image of the point A. Another pair of rays could be drawn from the point B of the object to locate its image B'.

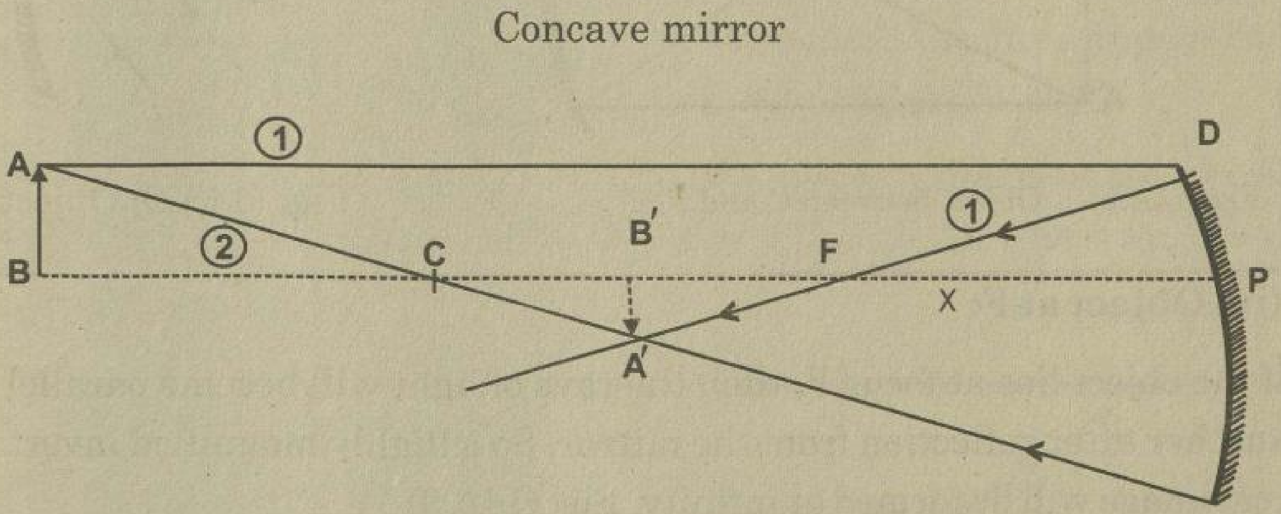


Fig. (14A.6) Object is beyond the radius of curvature

In general rays starting from each point of the object are reflected by the mirror. This results in the entire image of the object. The image formed is inverted and smaller in size than the object. It is a real image because the reflected rays really meet one another. Such an image can be obtained on a screen.

(ii) Object at C:

If the object is placed at the centre of curvature C of a concave mirror, the image formed is real, inverted and of the same size as the object. See Fig. (14A.7)

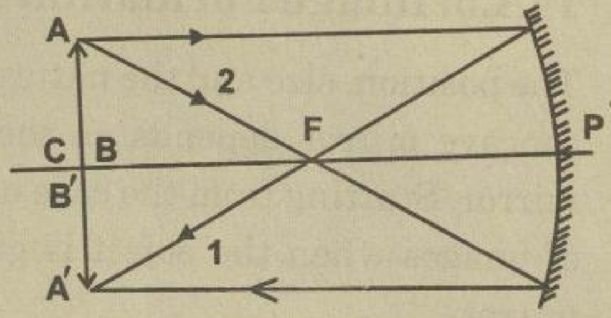


Fig.(14A.7)

(iii) Object between C and F

Moving the object from C towards F makes the image move further away from the mirror and becomes larger. The image is real and inverted. See Fig.(14A.8)

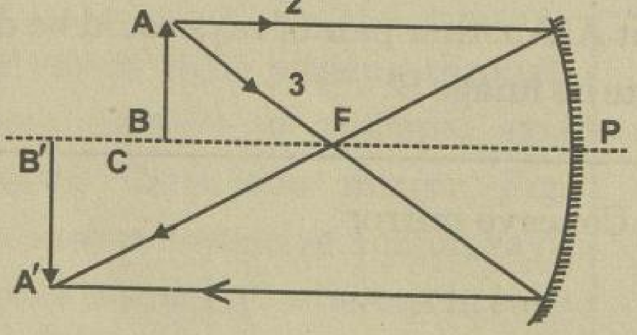


Fig.(14A.8) Object between C and F

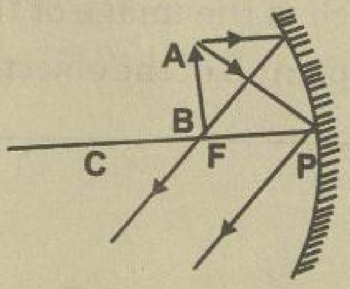


Fig. (14A.9) Object at F

(iv) Object at F:

If the object lies at focus F, then the rays of light will become parallel to one another after reflection from the mirror. So a highly magnified inverted and real image will be formed at infinity, Fig. (14A.9).

(v) Object Between F and P

If the object is kept between the focus and the pole of the concave mirror, then after reflection, rays of light diverge. So a real image is not formed in this case. Instead, a virtual erect and enlarged image A′B′ appears behind the mirror, Fig.(14A.10).

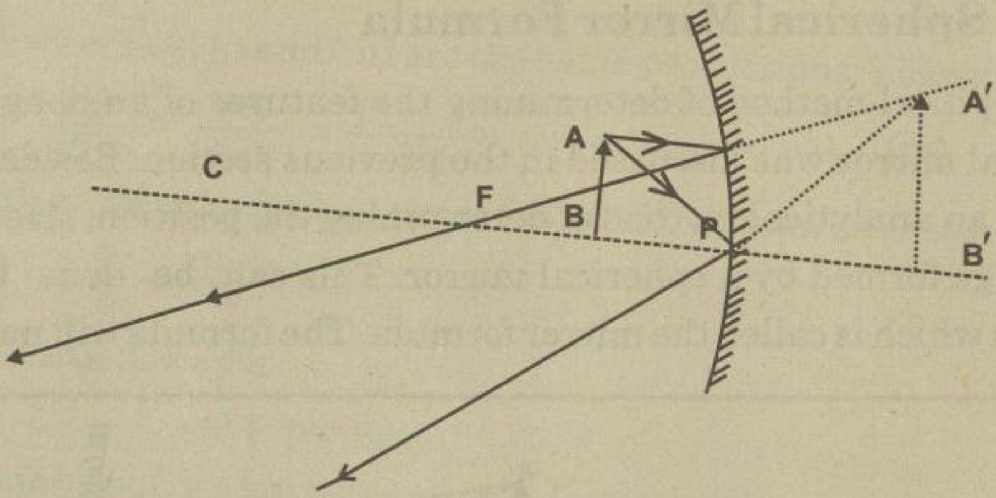


Fig.(14A.10) Object between F and P

14A.6 Image Formation By Convex Mirror

Let an object AB be placed in front of a convex mirror at any point on the principal axis of the mirror. A ray starting from A and parallel to the principal axis is reflected and appears to come from the virtual focus F. Another ray AP is reflected at the pole with angle of incidence equal to the angle of reflection at the pole. On extending, the two reflected rays diverge from each other. If they are extended backward, the rays appear to meet virtually at the point A′. Point A′ is the virtual image of point A.

Similarly, another pair of rays could be drawn from the point B of the object. Its virtual image is formed at B′ between P and F. In this way, the entire image A′B′ is formed.

The image A′B′ of the object AB is smaller than the object, upright, virtual and located between the pole and the focus irrespective of the position of the object.

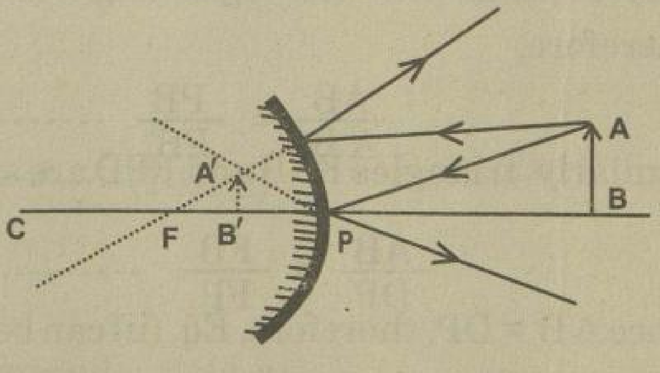


Fig. (14A.11) Image formation by convex mirror

14A.7 Spherical Mirror Formula

The graphical method of determining the features of an image formed by a spherical mirror was discussed in the previous section. Besides this method there is an analytical method of determining the position, size and nature of the image formed by a spherical mirror. This can be done by means a formula which is called the mirror formula. The formula will now be derived.

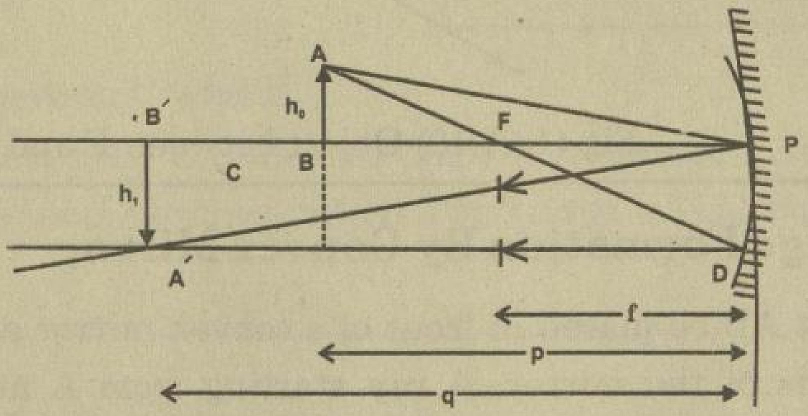


Fig.(14A.12). Derivation of spherical mirror formula

Let an object AB be placed at a distance p from pole of the mirror. In Fig. (14A.12), the object is between centre of curvature C and the focus F. Two rays AP and AD are incident on the mirror. After reflection from the mirror, the rays meet at point A'. Point A' is the image of A. Similarly the entire image A'B' is formed by the concave mirror shown in Fig.(14A.12). Let q be the distance of the image from the pole P of the mirror.

It is obvious that the right angle triangles PAB and PA'B' are similar. Therefore,

$$\frac{AB}{A'B'} = \frac{PB}{PB'} \quad \text{..................} \quad (i)$$

Similarly, triangles FAB and FPD are similar. Therefore,

$$\frac{AB}{DP} = \frac{FB}{FP} \quad \text{..................} \quad (ii)$$

Since A'B' = DP, therefore, Eq. (ii) can be written as

$$\frac{AB}{A'B'} = \frac{FB}{FP} \quad \text{..................} \quad (iii)$$

The left hand sides of Eqs. (i) and (iii) are the same proportions. Therefore,

$$\frac{PB}{PB'} = \frac{FB}{FP} = \frac{PB - FP}{FP} \quad \cdots\cdots\cdots\cdots\cdots \quad \text{(iv)}$$

If the focal length of the spherical mirror is f, then Eq. (iv) can be written as

$$\frac{p}{q} = \frac{p-f}{f}$$

By cross multiplication, we get

$$pf = pq - fq$$

Dividing both side by pqf, we have

$$\frac{1}{q} = \frac{1}{f} - \frac{1}{p}$$

or

$$\frac{1}{q} + \frac{1}{p} = \frac{1}{f} \qquad (14A.1)$$

This equation which relates the distance of the object and the image from the lens to the focal length of the lens is called the spherical mirror formula.

14A.8. Linear Magnification

The formation of images formed by spherical mirrors is shown in the various figures (14A.5-10). It is evident from these figures that by bringing the object closer or further away from the mirror, not only the position of the image changes but the nature and linear size of the image also change with it. The ratio of the size of the image to the size of the object is called linear magnification M:

$$M = \frac{\text{size of the image}}{\text{size of the object}}$$

$$M = \frac{A'B'}{AB} = \frac{p}{q} \quad \cdots\cdots\cdots\cdots\cdots \quad (14A.2)$$

Signs Convention:

While applying the spherical mirror formula (14A.1) in magnification formula (14A.2), the following signs convention is adopted to obtain the correct result in a given problem of image formation by a mirror.

i. All distances are measured from the pole of the mirror.

ii. Distances of real objects and real images are taken positive

iii. Distances of virtual objects and virtual images are taken as negative

iv. The focal length of a concave mirror is taken positive and that of a convex mirror is taken negative.

Use of Mirror and Magnification Formulas

We have already discussed that all real images are inverted and the virtual images are erect. Using the spherical mirror formula, we can find the position of the image. Similarly, by using the magnification formula, we can determine the size as well as the nature of the image.

We now present a few examples to illustrate the use of the mirror and magnification formulas.

Example14A.1. An object is placed at a distance of 18cm from a concave mirror. The focal length of the mirror is 6cm. The object is of height 3cm. How far from the mirror is the image formed? What will be the height of the image?

Solution

We use the common optical symbols.

$$p = 18\,\text{cm}$$

$$f = 6\,\text{cm}$$

$$q = ?$$

The spherical mirror formula is:

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

$$\frac{1}{6} = \frac{1}{18} + \frac{1}{q}$$

$$\Rightarrow \frac{1}{q} = \frac{1}{6} - \frac{1}{8} = \frac{3-1}{18} = \frac{1}{9}$$

$$q = 9\,\text{cm}$$

So, the image is formed at a distance of 9 cm from the mirror

To determine the magnification, we use the formula

$$\frac{\text{size of the image}}{\text{size of the object}} = \frac{p}{q}$$

$$\frac{\text{size of the image}}{3\text{ cm}} = \frac{9\text{ cm}}{18\text{ cm}}$$

$$\Rightarrow \quad \text{size of the image} = \frac{3\times 9}{18}\text{ cm} = 1.5\text{ cm}$$

Example 14A. 2: An object is located at a distance of 6 cm from a concave mirror. The radius of curvature of the mirror is 30 cm. Find how far, from the mirror the image will form. Mention the features of the image.

Solution:

Use the familiar symbols

$$p = 6\text{ cm}$$

$$f = \frac{r}{2} = \frac{30\text{ cm}}{2} = 15\text{ cm}$$

$$q = ?$$

The spherical mirror formula is

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

$$\frac{1}{15} = \frac{1}{6} + \frac{1}{q}$$

$$\Rightarrow \frac{1}{q} = \frac{1}{15} - \frac{1}{6} = \frac{2-5}{30} = -\frac{1}{10}$$

$$\Rightarrow q = -10\text{ cm.}$$

The image is formed at a distance of 10 cm from the pole, behind the mirror. It will be erect, virtual and enlarged, because, magnitude wise, q is greater than p.

Example 14A.3: A candle is located at a distance of 20 cm from a convex mirror. Its virtual image is formed behind the mirror at a distance of 4 cm from the mirror. The height of the candle is 10 cm. Find the focal length of the mirror and the size of the image.

Solution:

Use the common convention of optics:

$$p = 20\ \text{cm}$$

$$q = -4\ \text{cm}$$

$$f = ?$$

The spherical mirror formula is

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

$$\frac{1}{20} - \frac{1}{4} = \frac{1-5}{20} = -\frac{1}{5}$$

So the focal length of the convex mirror is 5 cm. The negative sign shows that the mirror is convex.

To find the size of the image, use the formula

$$\frac{\text{size of the image}}{\text{size of the object}} = \frac{p}{q}$$

$$\frac{\text{size of the image}}{10\ \text{cm}} = \frac{-4\ \text{cm}}{20\ \text{cm}}$$

$$\text{size of the image} = -2\ \text{cm}$$

Thus the height of the candle's image is 2 cm

14A.9: Uses of Spherical Mirrors

There are several important applications of spherical mirrors. A few of them are given as follows.

i. Convex mirrors are used in vehicles to observe rear view. It makes small, erect and virtual images of the objets behind the vehicle. This type of mirror collects together spread-out rays of light and thereby provides

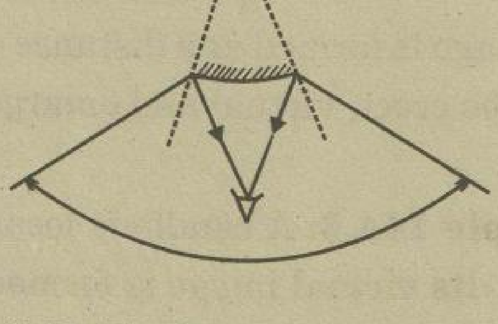


Fig.(14A.13) . A parallel beam created by concave mirror in a car head light a wide field of view. See Fig.(14A.13).

ii. Convex mirrors are also used at dangerous road bends for safe drive.

iii. Concave mirrors are used by doctors to examine ears, nose throat and eyes. The instrument used for this purpose is called ophthalmoscope. The virtual image formed by concave mirror is magnified. Therefore, it is often used for make-up and shaving.

iv. Concave mirrors are used in car head-lights, search light and spot light in operation room in a hospital.

v. Concave mirror are used to throw light on the slides of microscope so that the slides can be viewed more clearly. They are also used in the giant concave mirror telescopes.

vi. The concave dish is used to collect microwave signals from satellites to a focus.

SUMMARY

Reflection: When rays of light travelling in one medium are incident on the boundary of another medium, they bounce back. It is known as reflection of light.

Laws of Reflection:

(i) Angle of incidence is equal to the angle of reflection

(ii) The incident ray, the reflected ray and the normal to interface at the point of incidence lie in the same plane

Spherical Mirror: A section of a shining smooth spherical shell is called a spherical mirror. A spherical mirror whose outward budging surface is polished and reflecting is called a concave mirror. This type of mirror has the capability to converge a parallel beam of light.

- A spherical mirror whose inward curving surface is reflecting is called a convex mirror. The mirror has the ability to diverge a parallel beam of light.
- **Aperture:** The diameter of the circular boundary of a special mirror is called aperture.
- **Pole:** The geometric central point of a spherical mirror is called its pole.

- **Center of curvature:** The center of the sphere, of which the mirror is a part, is the center of curvature of the spherical mirror. The radians of this is the radians of the mirror.
- **Principle axis:** The straight line passing through the pole and the center of curvature is called the principle axis of the mirror.
- **Focus:** The point where parallel rays of light, after reflection from a spherical mirror, converge to or appear to diverge from, is called the focus of the mirror
- **Focal length:** The distance between the focus and the pole of a spherical mirror is called the focal length of a spherical mirror.

Image Formation by Concave Mirror:

If an object is placed beyond the focus of a concave mirror, its image will be real and inverted. The position and magnification of the image depends upon the position of the object.

If the object is between focus and pole, its image will be virtual, enlarged and behind the mirror.

Image Formation by Convex Mirror:

The image formed by a convex mirror is always virtual, diminished and between its pole and focus irrespective of the position of the object.

Spherical Mirror Formula:

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

Where p is the distance of the object, q is the distance o f the image from the mirror and f is the focal length of the mirror. The quantities p, q, f are positive for real objects and real images whereas they are negative for virtual objects and virtual images.

Magnification: The ratio of the size of the image to the size of the object is called magnification

$$M = \frac{\text{size of the image}}{\text{size of the object}} = \frac{p}{q}$$

OBJECTIVE QUESTIONS

I. Fill in the blanks

i. Light travel in a_______.

ii. The ray of light bouncing back from the interface of two media is called _______ ray.

iii. In reflection of light, the

  (a) angle of incidence is equal to the_______.

  (b) the incident ray, the reflected ray and_______ are coplanar.

iv. The reflection of light in which parallel ray are scattered in all direction is called _______.

v. Reflected rays when extended backward, appear to meet one another. The image will be_______.

vi. The image formed by a plane mirror is_______ inverted.

vii. The diameter of the circular boundary of a spherical mirror is called ______ of the mirror

viii. If a mirror is a part of a spherical shell, then it is called______

ix. The focus of a spherical mirror is at the ______ of the centre of curvature and the pole of the mirror.

x. The ratio of the size of the image to the size of the object is called _______.

2. Encircle T for true and F for false in the following statements.

i. Light spreads out in curved paths in all direction from a self luminous object. (T, F)

ii. When light is reflected by an opaque object, then all the light energy is reflected (T, F)

iii. In reflection of light, the incident ray and the reflected ray lie in two different planes (T, F)

iv. In regular reflection, the incident parallel rays remain parallel after the reflection. (T, F)

v. The diffuse light before the sun rise or after the sun set is due to the irregular reflection of light by the dust particles in the atmosphere. (T, F)

vi. The image formed in a plane mirror is real. (T, F)

vii. The inner surface of a convex mirror is polished. (T, F)

viii. Parallel rays of light are incident on a concave mirror. The rays will pass through the centre of curvature after reflection from the mirror. (T, F)

ix. An object is placed at the focus of a concave mirror. An enlarged image will be formed at infinity (T, F)

3. Complete the statement by selecting the correct option.

(i). In a reflection process, the angle of incidence is 30. The angle of reflection will be ______ **[10, 30 , 45 , 60]**

(ii). A boy is moving toward a plane mirror with velocity v. He will observe the velocity of his image towards the mirror to be **[-2v, 2v, -v, +v]**

(iii). An object is located at such a distance from a concave mirror that the size of the real image is the same as the size of the object. The focal length of the mirror is 10 cm. The distance of the object from the mirror will be **[5cm, 15cm, 20cm, 30cm]**

(iv). An object is placed at the centre of curvature of a concave mirror. It image will be ______ and ______.

(a) virtual, erect and enlarged
(b) real, inverted and diminished
(c) real, inverted and of the object size

4. SHORT ANSWER QUESTIONS

i. What is meant by reflection of light? State the laws of reflection of light.

ii. Distinguish between regular reflection and irregular reflection of light.

iii. Describe the importance of irregular reflection of light.

iv. Discuss the formation and the features of image formed by a plane mirror.

v. What do you understand by lateral inversion of an image? Explain.

vi. What is meant by a spherical mirror? Mention its kinds.

vii. Define the following terms used in connection with spherical mirrors:

(a) Centre of curvature (b) radius of curvature

(c) Concave mirror (d) convex mirror

viii. Compare concave and convex mirror with reference to the nature of the images formed by them.

ix. How would you make the rays from a luminous bulb parallel by means of a concave mirror.

x. What is meant by magnification of an image by a spherical mirror

5. COMPREHENSIVE QUESTIONS

i. What is meant by reflection of light? State the laws of reflection. Explain with diagrams.

ii. Distinguish between regular reflection and irregular reflection of light. Discuss the importance of regular reflection in every day life.

iii. What is a spherical mirror? How does it reflect light? Discuss the uses of spherical mirrors.

iv. An object is brought from a long distance towards a concave mirror. Discuss the feature of the image as the object is brought closer and closer. Support your discussion by drawing figures.

v. Distinguish between real image and a virtual image. Give the sign convention for the images formed by spherical mirror.

vi. Derive the spherical mirror equation for the case of a concave mirror.

NUMERICAL PROBLEMS

1. An object is placed at a distance of 4cm from a concave mirror. The radius of curvature of the mirror is 12cm. Where is the image formed? Discuss the features of the image.

   [Behind the mirror, 12cm distance, erect, and enlarged virtual]

2. A candle is placed at a distance of 15 cm from a concave mirror. The image is formed in front of the mirror at a distance of 10 cm from the mirror. Find the focal length of the mirror.

   [6 cm]

3. The radius of curvature of a concave mirror is 48 cm. The object is placed at a distance 30 cm from the mirror and the height of the object is 5 cm.
   (a) Where is the image formed?
   (b) What will be the size of the image?

   [20 cm in front of mirror, height 20 cm]

4. An object is placed at a distance of 60 cm from a convex mirror. The image is formed at 10 cm from the mirror. The height of the object is 12 cm.
   (a) Find the focal length of the mirror
   (b) Find the size of the image **[f = 12 cm, size is 2 cm]**

Chapter 14 B

REFRACTION OF LIGHT

In this chapter you will study

- The refraction of light
- The laws of refraction
- Refractive index of a medium
- Total internal reflection
- Critical angle and refractive index
- Prism and refraction by a prism
- Lenses and their kinds
- Formation of images by spherical lenses
- Thin lens formula
- Linear magnification
- Power of a lens
- Defects in lenses
- Eye and defects of vision

14B.1 REFRACTION OF LIGHT

You have studied in the previous chapter that, in a homogenous transparent medium, light travels in a straight line. However, when light is incident obliquely on the interface of two transparent media then some of the light is reflected back to the first medium and some of it enters into the second medium. The light bends slightly upon entering the second medium. The bending of light when it enters from one medium to another is called refraction of light. In Fig (14B.1), AB is the surface separating two media. The upper medium is air. The lower medium is another transparent medium such as water or glass

Let a ray of light CO be incident at point O of the surface AB. Upon entering the second medium, the ray changes its path. Instead of traveling along OD, the ray is refracted and travels along OE. The ray OE is called the refracted ray. Draw the normal NON′ Fig. (14B.1). The angle $C\hat{O}N = \theta$, is called the angle of incidence and the angle EON′ is called the angle of refraction. In the present discussion, the refracted ray bends towards the normal, that is, the angle of refraction is smaller than the angle of incidence

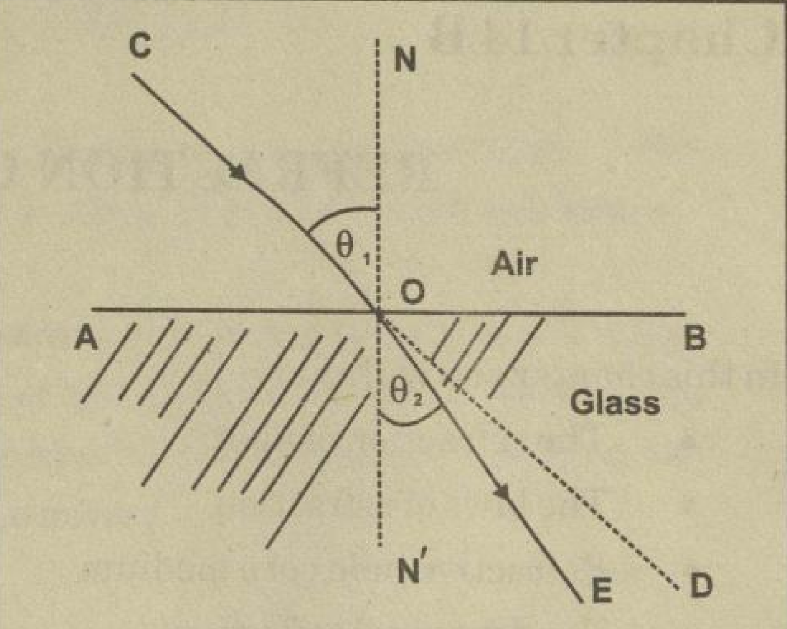


Fig.(14B.1) Refraction of light on entering a denser medium from a rarer medium

Conversely to the above example, Fig. (14B.2) shows light that travels through glass or water and enters air. In this case the refracted light bends away from the normal. We say that air is optically rarer than glass or glass is optically denser than air.

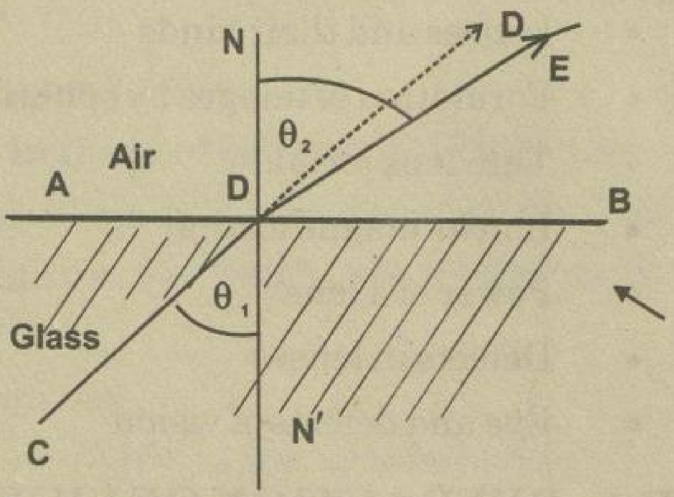


Fig.(14B.2) Refraction of light on entering rarer medium from a denser medium.

In general, when light enters from a rarer medium to a dense medium, it bends towards the normal. Conversely, when light enters from a denser medium to a rarer medium, it bends away from the normal.

Laws of Refraction

Refraction of light obeys the following two laws.

i. The incident ray, the refracted ray and the normal at the point of incidence are all in the same plane.

ii. The ratio of the sine of the angle of incidence θ_1 to the sine of the angle of refraction θ_2 is constant for a given pair of media. Mathematically

$$\frac{\sin\theta_1}{\sin\theta_2} = n$$

$$\sin\theta_1 = n_1 \sin\theta_2 \qquad (14B.1)$$

where n is a constants for a given pair of media. The constant 'n' is called the refractive index of the second medium with respect to the second medium. It is a ratio and has no unit.

The second law of refraction is also known as Snell's law.

It is obvious from Eq.(14B.1) that as the angle of incidence θ_1 decreases or increases, the angle of refraction θ_2 corresponds accordingly. Specially, when θ_1 becomes zero, θ_2 also reaches zero. This means that rays of light falling normally on the surface AB do not change their path. They enter the second medium normally. Normal incident light is not refracted.

Refractive Index

According to Snell's law, the refractive index n for a pair of transparent media is a constant. It is equal to the ratio

$$\frac{\sin\theta_1}{\sin\theta_2} = n$$

where θ_1 is the angle of incidence in the first medium and θ_2 is the angle of refraction is the second medium. The value of n does not depend on the angle of incidence θ_1. It depends on the nature of the two media.

The refractive index is closely related to the velocity of light in a transparent medium. In different media, light travels with different speeds. Its speed in vacuum is maximum and is equal to 3×10^8 ms^{-1}. The speed of light in air is almost the same as in vacuum. Experiment show that the relative refractive index for a pair of transparent medial is equal to the ratio of speeds of light in the two media. The refractive index of a medium relative to vacuum or air is the ratio of the speed of light in vacuum or air to the speed of light in the medium:

$$n = \frac{c}{v} = \frac{\text{speed of light in vacuum or air}}{\text{Speed of light in the medium}} \qquad (14B.2)$$

The refractive index of a medium is usually considered relative to vacuum or air.

Combining Eqs. (14B.1 and 14B.2), we see that the refractive index of a medium relative to vacuum or air is

$$n = \frac{\sin\theta_1}{\sin\theta_2} = \frac{c}{v} \qquad (14B.3)$$

As the speed of light is maximum in vacuum, we say that vacuum is optically the rarest medium. The greater the refractive index of a medium, the lower is the speed in the medium and is optically the denser medium. Table (14B.1) shows the refractive indices of a few media.

Example 14B.1 A ray of light is incident on surface o f water at 45° angle of incidence. The refractive index of water is 1.33. Find the angle of refraction of the refracted ray.

Solution:

The angle of incidence = $\theta_1 = 45^\circ$

The refractive index of water = $n = 1.33$

The angle of refraction = $\theta_2 = ?$

According to Snell's law: $n = \frac{\sin\theta_1}{\sin\theta_2}$

$$1.33 = \frac{\sin 45^\circ}{\sin\theta_2} = \frac{0.707}{\sin\theta_2}$$

$$\Rightarrow \sin\theta_2 = \frac{0.707}{1.33} = 0.53$$

Using calculator or tables of sines, we find that

$$\theta_1 = 32.1^\circ$$

Table 14B.1 Refractive Indices of Common Materials

Substance	Index of refraction	Substance	Index of refraction
vacuum	1.00000	Glycerine	1.47
Air	1.0003	Crown glass	1.52
Water	1.33	Flint glass	1.62
Ethyl Alcohol	1.36	Ruby	1.54
Quartz	1.46	Diamond	2.42
Sodium Chloride	1.53	Sulfuric acid	1.43
Benzene	1.501	Carbon dioxide	1.00045

Apparent and Real Depth

The apparent depth of objects under water is found to be less than their actual depth. Things immersed in water seem to be raised. What is the reason behind this effect? The reason is the refraction of light while coming out of water into air.

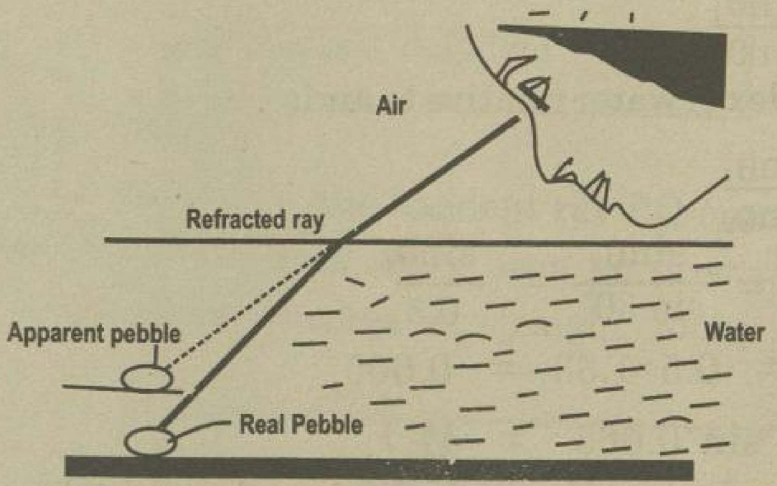


Fig.(14B.3). The real depth of objects immersed in water is less than the apparent depth of the objects.

In Fig. (14B.3), a pebble is lying at bottom of water. When the rays of light, coming from the pebble through water, enter into air, they are refracted away from the normal. It is evident from the figure that the rays of light entering into the eye seem to come from the apparently raised position. The apparent depth of the pebble is less than the real depth of the pebble.

With the help of the apparent depth and real depth of water in a container, we can calculate the refractive index of water.

$$\text{refractive index} = \frac{\text{Real depth}}{\text{Apparent dept}}$$

Example14B.2 A pebble is lying in a pond of water. A ray of light, starting from the stone, emerges out to the air. The angle of incidence in water to the air at water-air interface is 30°. The refractive index of water is 1.33. Find the angle of refraction in air. Illustrate the process with a diagram.

Solution

The angle of incidence in water is

$\theta_1 = 30^\circ$

The angle of refraction in air = $\theta_2 = ?$

By definition, the refractive index of air relative to water is

$$n_{wa} = \frac{\sin\theta_1}{\sin\theta_2}$$

The refractive index of water relative to air is

$$n_{wa} = \frac{\sin\theta_1}{\sin\theta_2}$$

$$1.33 = \frac{\sin\theta_2}{\sin 30^\circ} = \frac{\sin\theta_2}{0.5}$$

$$\Rightarrow \sin\theta_2 = 0.5\times1.33 = 0.665$$

$$\Rightarrow \theta_2 = \sin^{-1}0.665 = 41.7$$

The value of θ_2 is calculated by a calculator or the table of sines.

14B.2 Refraction of Light through Prism

A prism is a transparent refracting body, which is bounded by three rectangular and two triangular surfaces. It is shown in Fig. (14B.4). The angle between the two refracting rectangular surfaces that are opposite to the base is called the angle of prism.

The refraction of light through a glass prism is shown in Fig. (14B.5). The ray PQ strikes the face AB of the prism. On entering the prism, this ray bends towards the normal that is, towards the base of the prism. The ray proceeds along QR and is incident on the face AC of the prism. As the air outside the prism is rarer than glass, the emergent ray RS bends further towards the base of the prism.

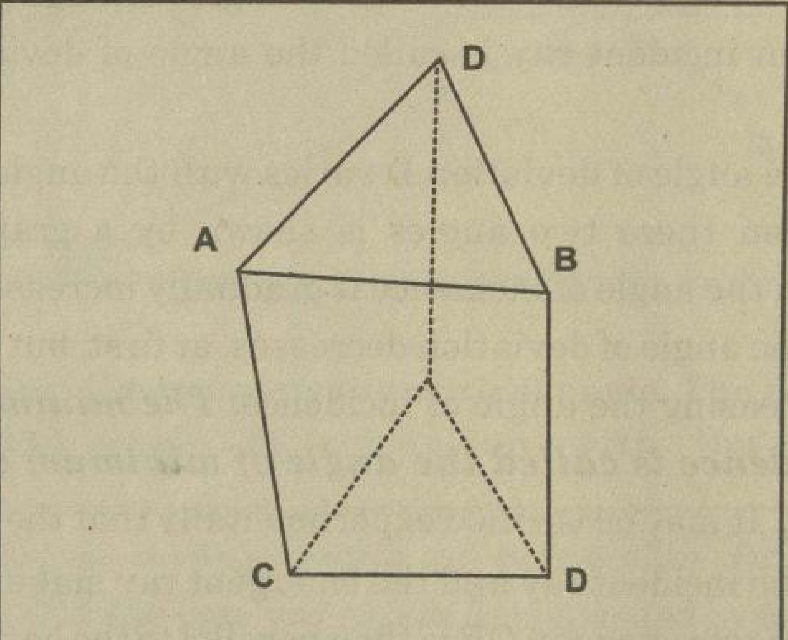


Fig.(14B.4). A Prism

Deviation of Light by a Prism:

It is evident from Fig (14B.5) that the incident ray PQ emerges out of the prism as the emergent ray PS. Had there been no prism in the path of incident ray, it would have proceeded straight along the direction

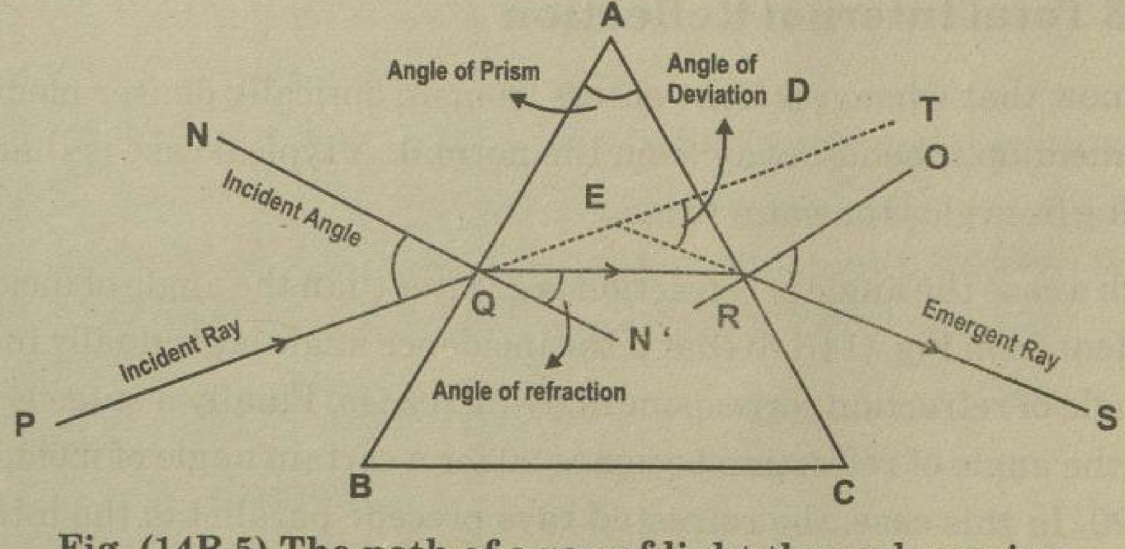

A
Angle of Prism
Angle of Deviation
D
T
O
N
Incident Angle
E
Q
R
N '
Incident Ray
Emergent Ray
Angle of refraction
P
S
B
C

Fig. (14B.5) The path of a ray of light through a prism

PQT. The prism has deviated the incident ray to the direction RS. Extend SP backward to meet PQT at the point E. ET is along the direction of incident ray and ES is along the direction of the emergent ray. The prism has deviated the incident through angle TÊS. This angle through which the prism deviates a given incident ray is called the angle of deviation and is often denoted by D.

The value of the angle of deviation D varies with the angle of incidence. The relation between these two angles is shown by a graph shown in Fig. (14B.5a). When the angle of incidence is gradually increased from its certain lowest value, the angle of deviation decreases, at first, but begins to increase by further increasing the angle of incidence. ***The minimum value of the angle of incidence is called the angle of minimum deviation and is denoted by D_m***. It may be verified experimentally that the angle of deviation is least when the incident ray and the emergent ray make equal angles with the normal. The refracted ray QR is then parallel to the base BC of the prism. The index of refraction of the material of which the prism is made can be determined by the relation.

$$n = \frac{\sin \frac{A + D_m}{2}}{\sin \frac{A}{2}}$$

where A is the angle of the prism and D_m is the angle of minimum deviation

14B.3 Total Internal Reflection

You know that whenever light enters from an optically denser medium to a rarer medium it bends away from the normal. A typical case is that of light entering from glass or water to air.

In such a case the angle of refraction is greater than the angle of incidence. It is evident from Fig. (14B.6) that if the incidence angle is gradually increased, the angle of refraction correspondingly increases. Finally a stage is reached when the angle of refraction becomes 90 for a certain angle of incidence less than 90. In this case, the refracted rays precede parallel to the interface of the two media. ***That angle of incidence in the optically rarer medium***

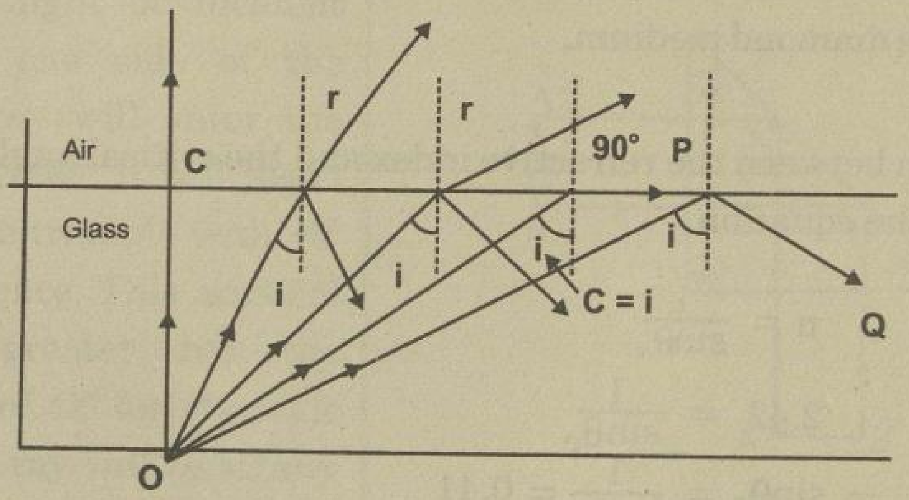


Fig.(14B.6). Angle C represents the critical angle. The refracted ray makes 90o angle of refraction with the normal

for which the corresponding angle of refraction in the denser medium is 90° is ***called the critical angle***. It is denoted by θ_c, Fig.(14B.6). The critical angles from water and glass to air are respectively 49° and 42°. When the angle of incidence in the denser medium becomes greater than the critical angle θ_c, there is no refracted beam. All the rays are internally reflected back in the optically denser medium. Such a reflection is called ***total internal reflection.***

The following conditions must be satisfied for the effect of total internal reflection

- The incident ray must enter from dense medium to a rarer medium
- The angle of incidence $\geq$ critical angle θ_c

There is an important relation between the critical angle and the refractive index of the pair of media. By definition, the critical angle is that angle in the denser medium for which the angle of refraction in the rare medium is 90°. Therefore, by Snell's law, for refraction from a denser medium into air

$$\frac{\sin\theta_c}{\sin 90^\circ} = \frac{n_{\text{rarer}}}{n_{\text{denser}}} = \frac{v}{c} = \frac{1}{n}$$

$$\Rightarrow n = \frac{c}{v} = \frac{\sin 90^\circ}{\sin\theta_c}$$

$$\Rightarrow = \frac{1}{\sin\theta_c} \qquad (\text{as } \sin 90^\circ = 1) \qquad (14B.6)$$

Example 14B.3: The refractive index of diamond is 2.42. Find the critical angle for the diamond medium.

Solution

The relation between the refractive index and the critical angle in a medium is given by the equation

$$n = \frac{1}{\sin\theta_c}$$

$$2.42 = \frac{1}{\sin\theta_c}$$

$$\Rightarrow \sin\theta_c = \frac{1}{2.42} = 0.41$$

$$\theta_c = \sin^{-1}(0.41) = 24.4^\circ$$

Example 14B.4: A ray of light OD enters normally to the side AB of equilateral right triangular glass prism. What will the direction of the ray after striking the point D. The critical angle for glass is 42°.

Solution

Ray OD is incident on the surface BC, which separates a denser glass medium from the rarer air medium. Draw the normal DN at D at the surface BC. Angle $O\hat{D}N$ is the angle of incidence in the denser medium. From the geometry of the triangle, it is obvious that angle $O\hat{D}N = 45^\circ$. As the critical angle for glass-air interface is 42° and is less than 45°, there will be total internal reflection at the point D. The ray OD will be reflected along DE with $N\hat{D}E = O\hat{D}N$.

Prism of TIR

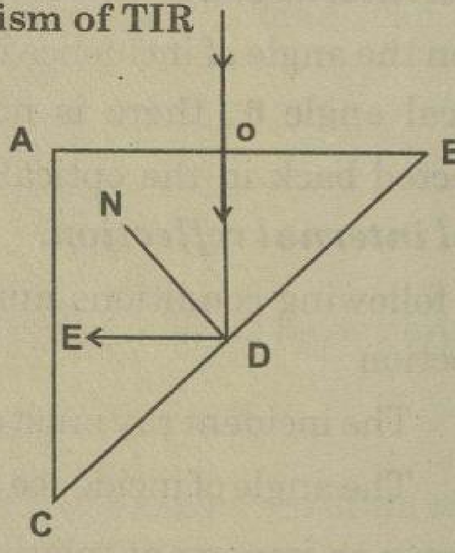


Fig.(14B.7)

Examples of Total Internal Reflection

(i) Totally Reflecting Prism

Fig. (14B.8) shows an equilateral right triangular glass prism.

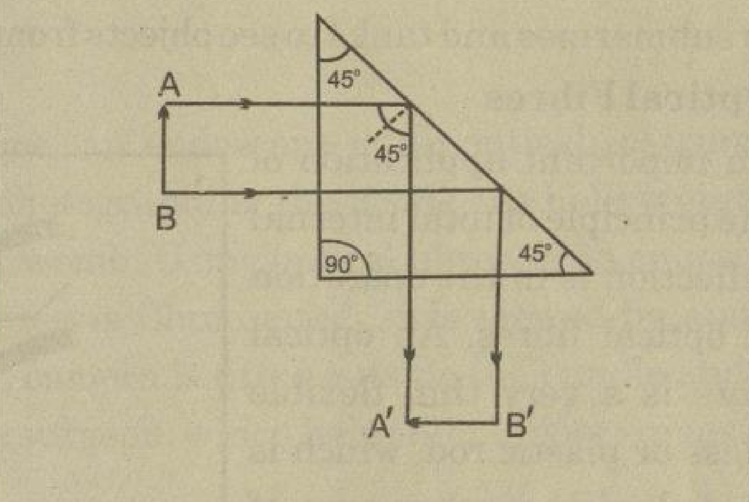


Fig.(14B.8) Totally reflecting prism

Let a ray of light be incident normally on one side of the prism. This ray will enter the prism un-deflected. It will reach the base of the triangle with 45° angle of incidence. This angle of incidence is greater than the critical angle of 42° for glass-air interface. The ray will be totally reflected internally with 45° angle of reflection. It will be incident normally on the other side of the prism and will come out of the prism un-deviated.

It is evident from the figure that the incident ray is deviated through angle of 90°. Fig. (14B.8) shows that rays coming from the object AB are deviated through an angle of 90° and emerge out of the prism as A′B′. Due to this fact the prism is used in periscope. Fig.(14B.8)

(ii)Periscope:

Periscope is an optical instrument, which can be used to see things that are not directly in sight. It works on the total internal reflection of light from two totally reflecting prisms. A periscope consists of a long metallic tube with equilateral right triangular glass prisms fixed at each end of the tube. Each of the prisms turns the incident light through 90°, Fig. (14B. 9) shows the construction and the working of a simple periscope. Making a periscope within the lawn of your house, you

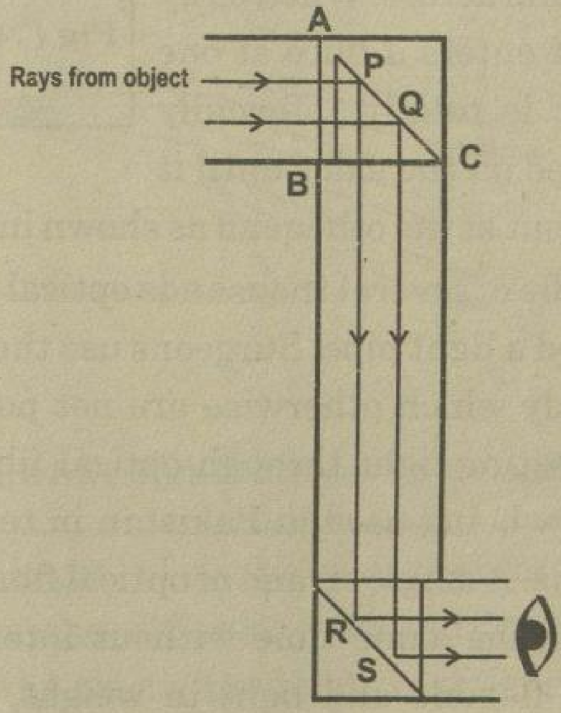


Fig.(14B.9) Periscope

can see objects outside the boundary wall of your house. Periscopes are used in submarines and tanks to see objects from a safer position.

Optical Fibres

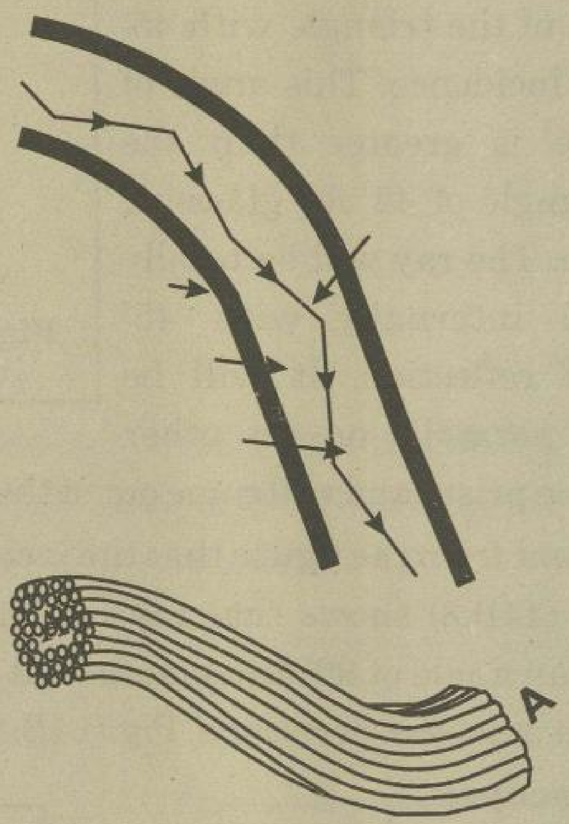


Fig.(14B.10). Optical fibre and optical pipe

An important application of the principle of total internal reflection is in the operation of optical fibres. An optical fibre is a very thin flexible glass or plastic rod, which is coated with another type of glass whose refractive index is less than the inner tube. Generally, the refractive index of the inner tube is 1.52 and that of the coating is 1.48. The thickness of the fibre is about the thickness of human hair, that is, about 1/100 mm across. When a ray of light enters a fibre at one end, it is totally internally reflected off the sides until it comes out at the other end as shown in Fig. (14B.10).

A bundle of several thousands optical fibres bound together in a flexible tube is called a light pipe. Surgeons use them to see on a screen those parts inside the body which otherwise are not possible to examine. The energy loss in propagating light through optical fibres is extremely small. Optical fibres are now being used in Pakistan in telephone and other telecommunication systems. A single strand of optical fibre can transmit thousands of telephone calls at the same time without interfering each other. Optical fibres are highly flexible and light in weight. They are cheaper as compared with copper cables. Generally, a cable consists of a bundle of 30 optical fibres. The transmitting capacity of light pipes is thousands of times greater than the radio waves.

Endoscope:

Like telescope and a microscope, an endoscope is an optical instrument, which is used for viewing and photographing the inside of a hollow organ of the body such as the bladder or womb. Using optical fibres in an endoscope, the part of the body to be viewed is illuminated. It is viewed by another bundle of optical fibres. A video camera is fitted outside the bundle and this makes the interior visible to the surgeon, which helps him to operate easily.

14B.4 Dispersion of Light

An experimental arrangement illustrated in Fig. (14B.11) shows that when a beam of white sunlight passes through the glass prism, the light splits into a range of seven colours: violet, indigo, blue green, yellow, orange and red. This experiment shows that white light is not of a single colour but is composed of various colours.

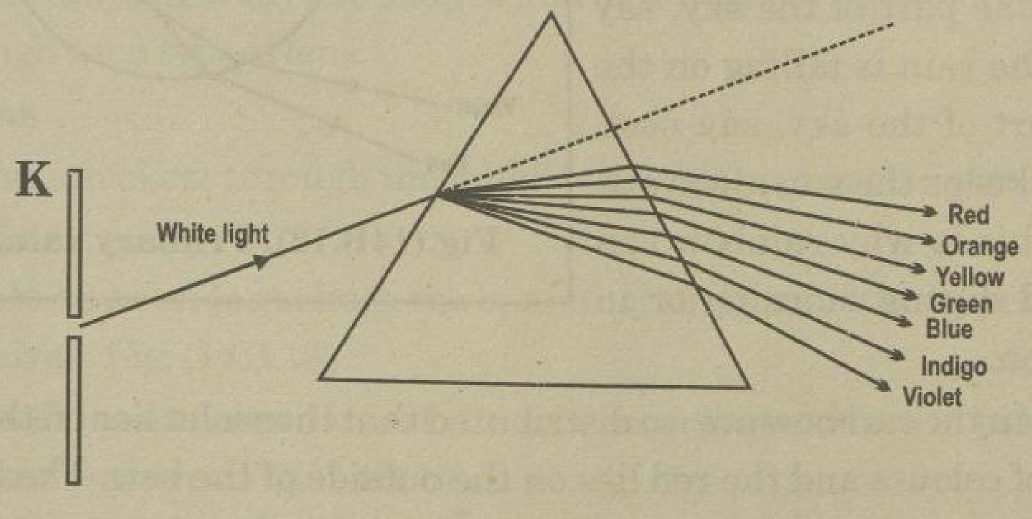


Fig.(14B.11) Dispersion of white light into seven colours

How do we get the coloured lights? Lights of all the colours enter the prism together. The glass prism refracts the different coloured light through different angles. On coming out of the prism, the lights of different colours are refracted once again through different angles. The coloured lights are waves of different wavelengths and different frequencies. When they pass through a glass prism, refraction takes place. The waves of shortest wavelengths bend more than those of longer wavelengths. Thus different coloured lights in the white light will separate into a spectrum of colours. The shortest wavelength visible to the eye is violet with wavelength 0.4μm and its deviation is the greatest. Red light has the longest wavelength:$\lambda \approx 0.7\mu$m. It is deviated the least by the prism.

14B. 4A Rainbow

You may have observed a rainbow. It is usually observed after a rain. It is produced by the dispersion of white sunlight into seven colours by the droplets of water suspended in the atmosphere. Each droplet acts like a prism. It refracts as well as disperses the sunlight into its spectrum colours, Fig.(14B.12). A rainbow is seen when the sun is shining in one part of the sky, say west, and the rain is falling on the opposite part of the sky, say east. The viewer keeps the sun always at his back. This is why rainbow can be observed during morning or in the afternoon.

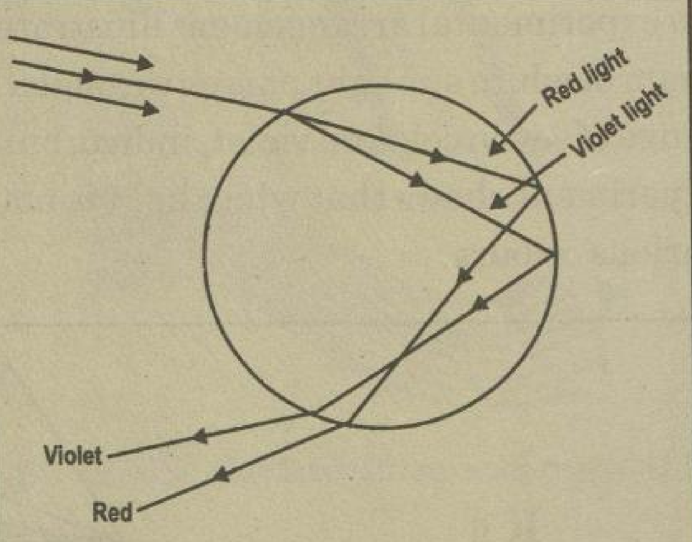


Fig.(14B.12). Primary rainbow

The colours in the rainbow are so distributed that the violet lies on the inside of the bow of colours and the red lies on the outside of the bow. The rainbow described above is called primary rainbow. It has bright colours and is easily visible.

Secondary Rainbow

Sometimes a secondary rainbow beyond the outer edge of the primary rainbow is seen. Secondary rainbow is fainter than primary rainbow and is seldom visible. This is produced when the rays from the sun suffer double internal reflection, Fig. (14B.13). Due to two internal reflections in the water droplets, the colour bands of the secondary rainbow are in reverse order of the bands in primary rainbow. Their order is violet, indigo, blue, green, yellow, orange and red.

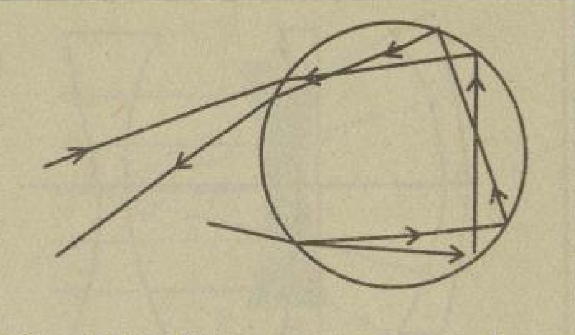


Fig.(14B.13).Secondary rainbow

14B.5 Lenses

Millions of people wear spectacles to see things clearly. Cameras are used for photography. Projectors are used to show films on screen. Tiny organisms are examined with the help of microscopes. Distant objects, planets and heavenly bodies are observed through telescopes. All these optical instruments do make some use of lenses and refraction of light.

Lenses are bodies of transparent material, usually glass, shaped so to converge or diverge a beam of light. Simple lenses are bounded by faces, which are small sections of spheres. Rays of light refract in passing through a lens. Two main types of lenses are in general use. They are convex lens and concave lens. Now will study the shapes and of the lenses and the refraction of light through each type of lens.

Convex Lens

A convex lens is thickest through the middle and thinnest at the edges. It has three sub-types

a) **Double convex lens:** Both the bounding surfaces of this types of lens are convex, Fig. (14B.14)

b) **Plano-Convex lens:** One of the two bounding surface is plane and the other is convex Fig. (14B.14)

c) **Concave-Convex lens:** One bounding surfaces is concave and the other is convex, Fig. (14B. 14)

Concave Lens

A concave lens is thinnest in the middle and thickest at the edges. The three sub-types of this are: double concave lens; plano-concave lens and convexo-concave lens, Fig. (14B.14)

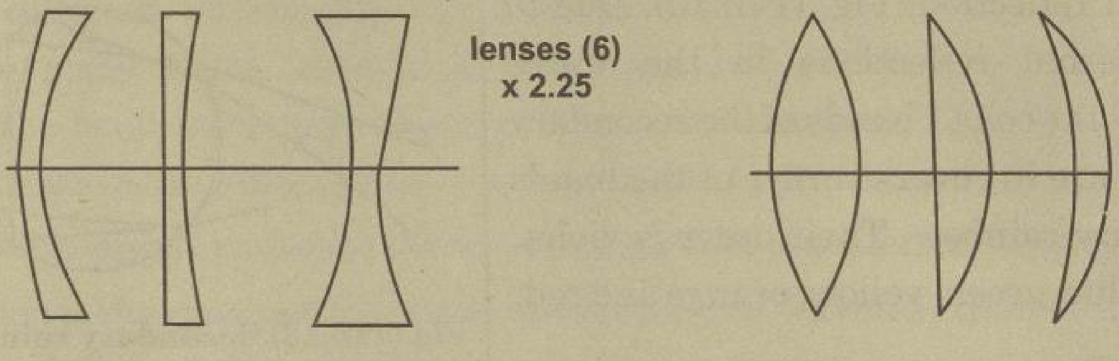
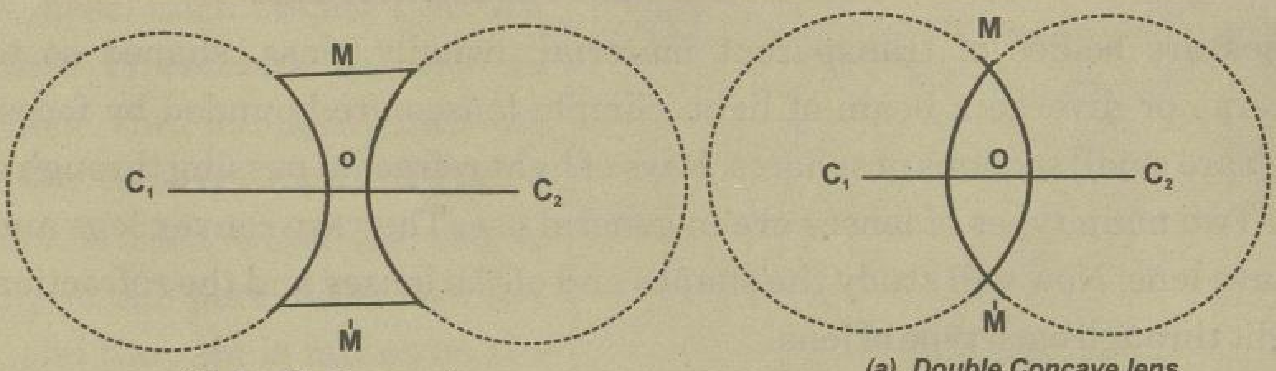


Fig. (14B.14) concave lenses **Convex lenses**

Definitions of Special Terms

A few of the terms used in lens optics are defined as follows.



(b) Double Concave lens

(a) Double Concave lens

Fig.(14B.15). Geometry of lenses

Centre of Curvature C:

Each of the curved surfaces of a lens has a centre of curvature. Therefore, a curved lens has two centres of curvature C_1 and C_2, Fig. (14B.15)

Principal Axis

The line joining the two centres of curvature C_1 and C_2 of a lens is called the principal axis. Fig.(14B.15).

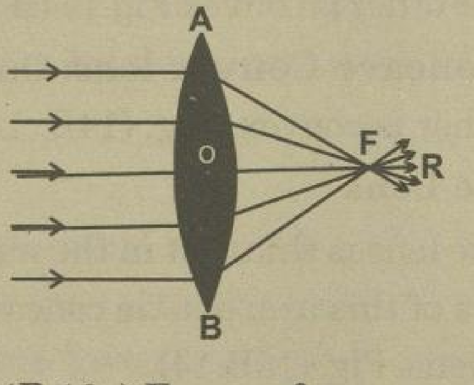


Fig.(14B.16a) Focus of a convex lens

Optical Centre O

There is a particular point O in a lens called its centre such that any ray passing through this point does not suffer any change in its direction. Optical centre O of a lens always lies on the principal axis as shown in Fig. (14B.15). All optical distances are measured from the centre O of the lens.

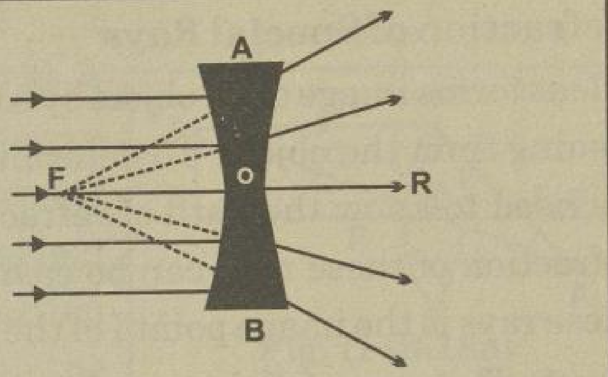


Fig.(14B.16b) Focus of a concave lens

Principal Focus

The point F where all rays parallel to the principal axis meet after passing through a convex lens or appear to diverge from F after passing through a concave lens. The point F is called the principal focus, Figs. (14B.16 a, b). Each type of lens has two principal foci, one on each side of the lens. For symmetrical thin lenses, the two foci are equidistant from the lens.

Focal length

The distance f between the principal focus F and the optical centre O of the lens is called the focal length of the lens.

Aperture

The central transparent region bounded by the boundary of the lens is called the aperture. It is specified by the diameter of the circular region exposed to the incident light.

Signs Convention

Lenses form images of objects. All distances are measured from the optical centre O of the lens. Distances of real objects and real images from the lens are considered positive whereas the distances of virtual objects and virtual images are considered negative. Because of the signs convention, the focal length of a convex lens is taken positive and that of a concave lens is considered negative.

Refraction of Special Rays

A lens forms image of an object by converging or diverging the numerous rays coming from the object. To determine the location and nature of the image, we need to know the path of refraction of only three rays. The direction of refraction of these rays can be easily predicted. The point of intersection of these rays is the image point I of the object-point.

Ray1: This ray of light parallel to the principal axis passes through the principal focus F after refraction from the lens. In case of convex lens, ray1 actually passes through F. In case of a concave lens, the ray appears to pass through F, Fig.(14B.17)

Ray 2: This ray of light passing through the principal focus becomes parallel to the principal focus after refraction from the lens, Fig. (14B.17)

Ray 3: This ray through the optical centre of the lens passes through the lens undeviated, Fig. (14B.17).

14B.6 Image Formation by Convex Lens

The position, nature and size of the image of an object that is formed by a given convex lens depend on the distance of the object from the lens. Fig. (14B.18a) to Fig (14B.18e) show the formation of image when an object is gradually brought closer the lens. The following cases illustrate the graphical ray diagram method of constructing the images of an object.

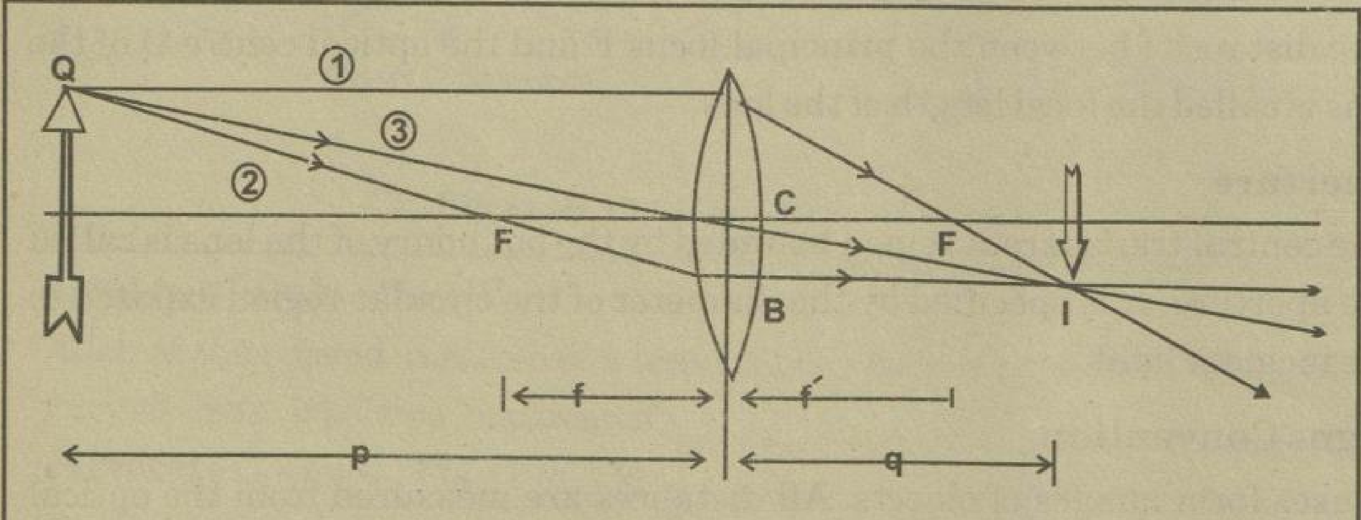


Fig. (14B.17): The special ray in refraction through a lens

i. Object Placed beyond 2f or (C)

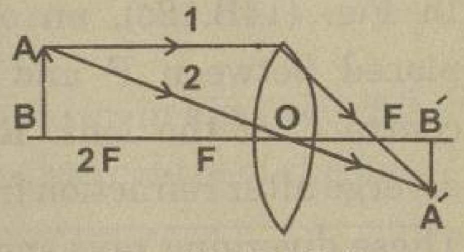


Fig. (14B.18a)

In Fig. (14B.18a), an arrow object AB is placed at distance greater than 2f. Observe the rays 1 and 2 that start from a point A of the object. Ray 1, parallel to the principal axis, will pass through F after refraction through the lens. Ray 2 passes through the optical centre O undeviated. The two rays meet at the point A′. The point A′ is the image of the point A. Similarly an image of every point of the object is formed. A′B′ is the image of AB. The image is real, inverted and diminished.

ii. Object Placed at 2f or (at C)

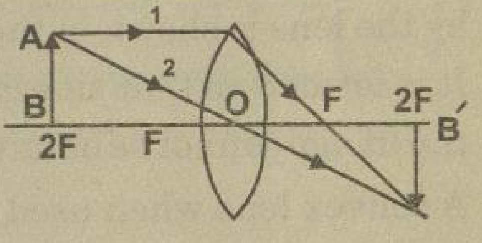


Fig. (14B.18b)

When the object is placed at 2f, the image formed will be at 2f, as shown in Fig. (14B.18b). The image will be real, inverted and of the same size as the object.

iii. Object is between 2f and f.

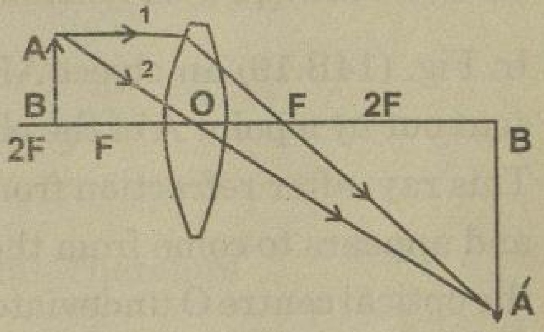


Fig. (14B.18c)

This situation is shown in Fig. (14B.18c). The two rays 1 and 2 starting from point meet to form its image at A′. Similarly B′ is formed from B. The image is formed beyond 2f. The image is real, inverted and magnified. Film projectors use this type of optical arrangement.

iv. Object at Focus F

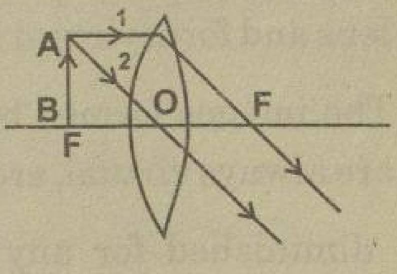


Fig. (14B.18d)

When the object is at F, its image will be at infinity much enlarged, real and inverted as shown in Fig. (14B.18d)

v. Object between F and the Lens

In Fig. (14B.18e), an object AB is placed between F and the optical centre C of the lens. Ray 1 and 2 diverge after refraction from the lens. These diverging rays spread out and do not meet anywhere. However, if the rays are traced backward, they appear to meet at the point A′. The point A′ is the virtual image of the point A. The entire image A′B′ formed by the lens is shown in the figure. The image is virtual, erect and magnified. It is formed on that side of the lens where the object is placed. Being virtual, the image cannot be obtained on a screen. The eye can see the image.

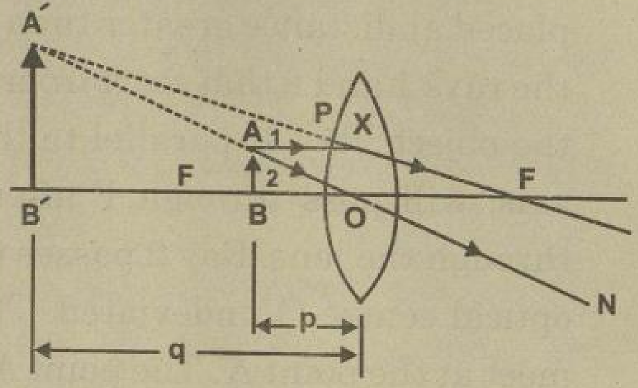


Fig. (14B.18e)

A convex lens when used in the arrangement to magnify the object is known as a magnifying glass.

14B.7 Image Formation by Concave Lens

In Fig. (14B.19) an object AB is placed in front of a concave mirror. Ray 1, sent out by a point A of the object is parallel to the principal axis of the lens. This ray, after refraction from the lens, moves away from the principal axis and appears to come from the focus F of the lens. The ray 2 passes through the optical centre O undeviated. They two rays diverge after passing through the lens. They appear to meet at the point A′ shown in Fig. (14B.19). Point A′ is virtual image of the point A of the object. In this ways the rays coming from the object AB refract through the lens and form virtual image A′B′

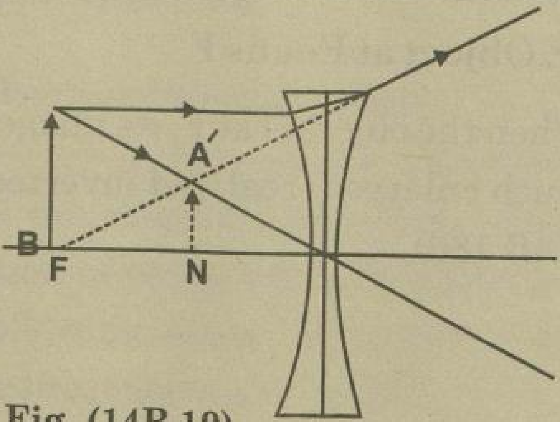


Fig. (14B.19)

The images formed by a concave lens are always virtual, erect and

diminished for any position of the object. The images are formed on the same side as the object and always in between the object and the lens.

14B.8 Lens Formula

An object AB and its image A′B′ in a convex mirror are shown in Fig. (14B.20). The distances of the object and the image from the optical centre of the lens are respectively p and q. Let the focal length of the lens be f. The relation between p, q and f is called the lens formula. Let us now derive this formula.

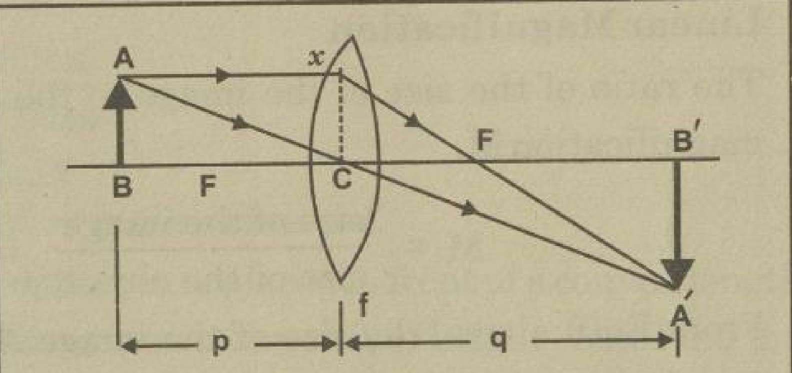


Fig.(14B.20). Thin lens formula diagram

It is obvious from the figure that the right angle triangles CAB and CA′B′ are similar. Therefore,

$$\frac{A'B'}{AB} = \frac{CB'}{CB} \qquad \text{(i)}$$

Similarly triangles FA′B′ and FXC are similar and

$$\frac{A'B'}{CX} = \frac{FB'}{FC} \qquad \text{(ii)}$$

Since AB = CX, therefore, Eq(ii) can be written as

$$\frac{A'B'}{AB} = \frac{FB'}{FC} \qquad \text{(iii)}$$

The left hand side ratios in Eqs (i) and (iii) are equal. Therefore

$$\frac{CB'}{CB} = \frac{FB'}{FC}$$

$$= \frac{CB' - FC}{CB} \qquad \text{(iv)}$$

Using the commonly used symbols f, p, q for these distance, Eq. (iv) can be written as

$$\frac{q}{p} = \frac{q - f}{f}$$

By cross multiplication, we get

$$qf = pq - pf$$

Dividing both side by pqf, we have

$$\frac{1}{p} = \frac{1}{f} - \frac{1}{q}$$

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f} \qquad (14B.1)$$

This equation is called the lens formula

Linear Magnification

The ratio of the size of the image to the size of the object is called linear magnification M.

$$M = \frac{\text{size of the image}}{\text{size of the object}} = \frac{A'B'}{AB}$$

From Eq(i) above, the size of the image A′B′ to the size of the object AB is equal to the ratio $\frac{q}{p}$. Therefore

$$M = \frac{A'B'}{AB} = \frac{q}{p} \qquad (14B.2)$$

Example 14B.5: An object of height 4 cm is placed in front of a lens of focal length 12 cm. The distance of the object from the lens is 15 cm. Find the position, nature and size of the image formed by the lens.

Solution:

Use the commonly used symbols of optics:

Size of the object = 4 cm

$p = 15$ cm, $f = 12$ cm, $q = ?$

As f is positive, the lens is convex.

The lens formula is

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$

$$\Rightarrow \frac{1}{p} = \frac{1}{f} - \frac{1}{q}$$

$$= \frac{p-f}{fp}$$

$$\Rightarrow q = \frac{fp}{p-f}$$

Put the given values in this equation

$$q = \frac{12\text{cm} - 15\text{cm}}{(15 - 12)\text{cm}} = 60 \text{ cm.}$$

Use the magnification formula.

$$M = \frac{A'B'}{AB} = \frac{q}{p}$$

$$\frac{A'B'}{4\text{cm}} = \frac{60\text{cm}}{15\text{cm}}$$

$$\Rightarrow A'B' = 16\text{cm}$$

Since M is positive, the image will be real an inverted.

Example 14B. 6. An object of height 2cm is placed in front of a convex length of focal length 10cm. The image formed on a screen is of height 4cm.Find the distances of the object as well as the image from the lens.

Solution

Use the commonly used symbols:

$f = 10 \text{ cm}$

$AB = 2 \text{ cm}$

$A'B' = 4 \text{ cm}$

$p = ?$

$q = ?$

The magnification

$$M = \frac{q}{p} = \frac{A'B'}{AB} = \frac{4\text{cm}}{2\text{cm}} = 2$$

$$\Rightarrow q = 2p \qquad \text{(i)}$$

The lens formula

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

put the values of f and q in this equality

$$\frac{1}{10\text{cm}} = \frac{1}{p} + \frac{1}{2p}$$

$$= \frac{2+1}{2p} = \frac{3}{2p}$$

$$\Rightarrow p = \frac{3 \times 10\text{cm}}{2} = 15\text{cm}$$

$$\Rightarrow q = 2p = 2 \times 15 \text{ cm} = 30\text{cm}$$

Example 14 B.7: An object of height 2 cm is placed in front of a convex mirror of focal length 20 cm. It is required to have an image of size thrice the size of the object. Where the object should be placed to have such an image?

Solution:

There are two positions of the object for which the image is magnified as compared with the object. In one case, the object is between f and 2f and the image is real. In the second case, the object is between f and the lens. The image is then virtual.

Case i: Real Image

$$f = 20 \text{ cm}$$

$$M = 3$$

As $M = \frac{q}{p} = 3 \Rightarrow 3p$

The lens formula is

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

Put the values of f and q in this equation

$$\frac{1}{20\text{cm}} = \frac{1}{3p} + \frac{1}{p}$$

$$= \frac{1+3}{3p} = \frac{4}{3p}$$

$$\Rightarrow p = \frac{4 \times 20\text{cm}}{3} = 26.6\text{cm}$$

and $q = 3p = 80 \text{ cm}.$

Case ii: Virtual Image

$$M = -3$$

$$\frac{q}{p} = -3 \Rightarrow -3p = q$$

The lens formula is

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

$$\frac{1}{20cm} = \frac{1}{-3p} + \frac{1}{p} = \frac{-1+3}{3p} = \frac{2}{3p}$$

$$\Rightarrow \quad p = \frac{2\ \ 20cm}{3} = 13.3cm$$

Example 14B.8: An object is placed in front of a convex lens so that its real image is twice the size of object. If the focal length of the lens is 10cm, find the distance between the object as its image.

$$f = 10cm$$

and $$M = \frac{q}{p} = \frac{A'B'}{AB} = 2$$

$$q = 2p$$

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

$$\frac{1}{10cm} = \frac{1}{p} + \frac{1}{2p} = \frac{2+1}{2p} = \frac{3}{2p}$$

or $2P = 10cm \times 3 = 30cm$

so $q = 30cm$

as $q = 2P$

so $30\ cm = 2P$

or $$P = \frac{30cm}{2} = 15\ cm$$

Therefore, distance between object and image = $P + q = 15\ cm + 30\ cm = 45\ cm$

Example 14B.9: An object of size 5cm is placed at a distance of 20cm from a concave lens of focal length -10cm. Find the position and the size of the image

Solution:

In terms of the commonly used symbols

$$f = -10cm$$

$$p = 20cm$$

$q = \quad ?$

Size of the object $\quad AB = 5cm.$

The lens formula is

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

$$\Rightarrow \quad \frac{1}{q} = \frac{1}{f} - \frac{1}{p} = \frac{p-f}{fp}$$

$$\Rightarrow \quad q = \frac{fp}{p-f} = \frac{(-10cm) \times 20cm}{20cm - (-10)}$$

$$q = \frac{10 \times 20}{30} cm = -\ 6.6cm.$$

Magnification is given by

$$\frac{A'B'}{AB} = \frac{q}{p}$$

$$\Rightarrow \quad \frac{A'B'}{5cm} = \frac{-6.6cm}{20cm}$$

$$A'B' = -\ \frac{5 \quad 6.6}{20}\ cm$$

$$A'B' = -\ 1.6cm$$

The negative sign shows that the image is virtual. It is diminished as compared with the size 5cm of the object.

14B.9 Power of Lens

A lens tends to converge or to diverge a beam of light, passing through it, to a focus. The smaller the focal length the greater is the convergence or divergence power of the lens. Thus the reciprocal of the focal length f of lens is defined as the power of the lens, where f is expressed in metres. It is denoted by D.

$$D = \frac{1}{f} \quad \text{(f is in metres)}$$

The power of a lens is measured in dioptres. One dioptre is the power of a lens of one metre focal length. If the focal length of a lens is 25cm then f = 25cm = 0.25m. Its power is

$$D = \frac{1}{0.25\text{m}} = 4 \text{ dioptre.}$$

Let the lens power of the spectacles of a person is +2.5dioptre, This means that the focal length of the lens is $\frac{1}{25}$ m = 40cm. The power of a convex lens is positive and that of concave lens is negative.

Example 14B.10: A lens of power -1.25 dioptre is used in spectacles. Find the focal length and the type of the lens.

Solution:

The power of the lens is negative. Therefore, the lens is concave.

The power of the lens is

$$D = \frac{1}{f}$$

$$\Rightarrow f = \frac{1}{D} = \frac{1}{-1.25 \text{ dioptre}}$$

$$= 0.80 \text{ m}$$

$$\Rightarrow f = 80 \text{ cm.}$$

In optical instruments, lenses are combined together in contact. If D_1 and D_2 are power of two lenses of focal lengths f_1 and f_2 and are placed in contact, then the power of the combination is given by

$$D = D_1 + D_2 = \frac{1}{f_1} + \frac{1}{f_2}$$

14B.10 Defects in Lenses

Images formed by a lens are, in general, not exactly identical to the objects. Lenses suffer from two common types of defects: Spherical aberration and chromatic aberration.

Spherical Aberration: A beam of parallel rays is focused at a point by a lens only if the aperture of the lens is small, otherwise the lens will refract outer rays slightly more than the inner rays Fig. (14B.21). The image produced will not be well defined and sharp. This defect of a lens by which rays entering near the edge of the lens than the rays that enter near the centre is called spherical aberration. Using a diaphragm in front of the lens can minimize the aberration. The diaphragm decreases the effective aperture of the lens.

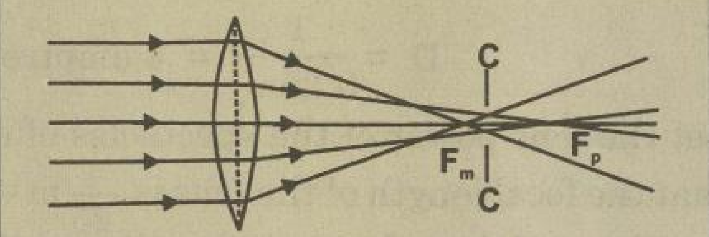


Fig.(14B.21). Spherical aberration

Chromatic Aberration

A lens act like a prism placed base-to-base or end-to-end. Thus white light passing through a lens is refracted as well as dispersed.

Different coloured lights are brought to focus at different distances from the lens, Fig. (14B.22). Violet light is focused closest and red light is focused furthest. As a result, the image is not sharp and has coloured markings. ***This image defect is called chromatic aberration. It is the inability of the lens to bring to a focus all the dispersed colours at one single point.*** This defect can be corrected, to a large extent, by combining a convex lens of crown glass and a concave lens of flint glass in such a way that dispersion of light produced by convex lens is neutralized by the concave lens. Such a combination of lenses is an achromatic lens, Fig.(14B.22). Combinations of lenses are used in high-class optical instruments.

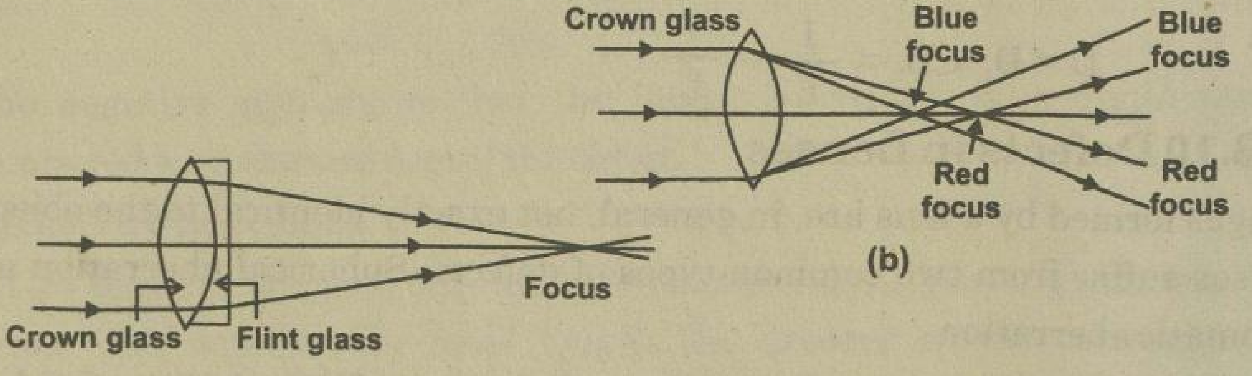


Fig. (14B.22) Illustration of chromatic aberration

14B.11. The Human Eye

The human eye, shown in Fig.(14B.23) is, in fact, a convex lens system that forms a small upside-down image of anything in front of it. The various parts of the eye are shown in Fig. (14B.23). The image is formed on the retina of the eye. Light enters the eye through the **cornea**. Behind the cornea is the coloured iris diaphragm. The iris controls the amount of light entering the eye. In darkness, the **pupil** hole in the middle of the iris grows larger. The cornea and the watery liquid behind it do most of the focusing of the rays of light.

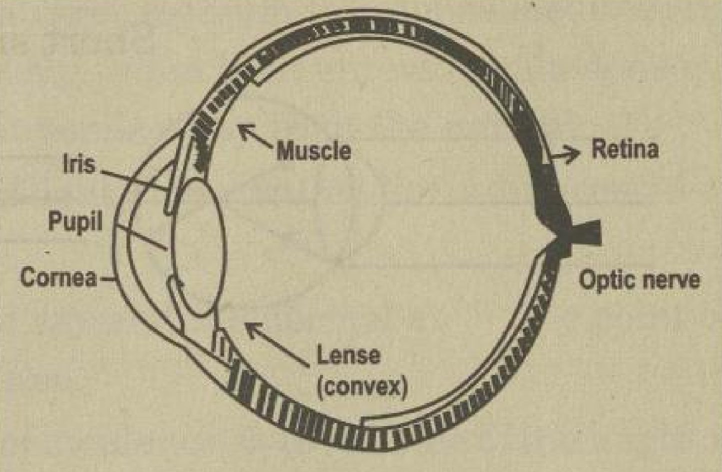


Fig. (14B.23)

The retina is the screen, which detects the image. Retina has a composition of nerves. These nerves are attached to the optic nerve, which carries information from the retina to the brain. The brain gives an upright view of the world.

Defects of Vision

Sometimes, a lack of coordination among the different parts of the eye gives rise to defects in vision. A few of these defects and their remedial measures are now discussed.

Short-Sightedness (myopia)

The defect, in which an eye can see near objects clearly but distant objects are not clearly seen, is called shortsightedness. The lens of such an eye is more convergent than that of the normal eye. The eyeball is too long for the lens system. The parallel rays from the distant object are focused just in front of the retina. A concave lens is placed in front of the eye to correct the fault as shown in Fig. (14B.24). The combination of the two lens forms the image on the retina.

Short sight

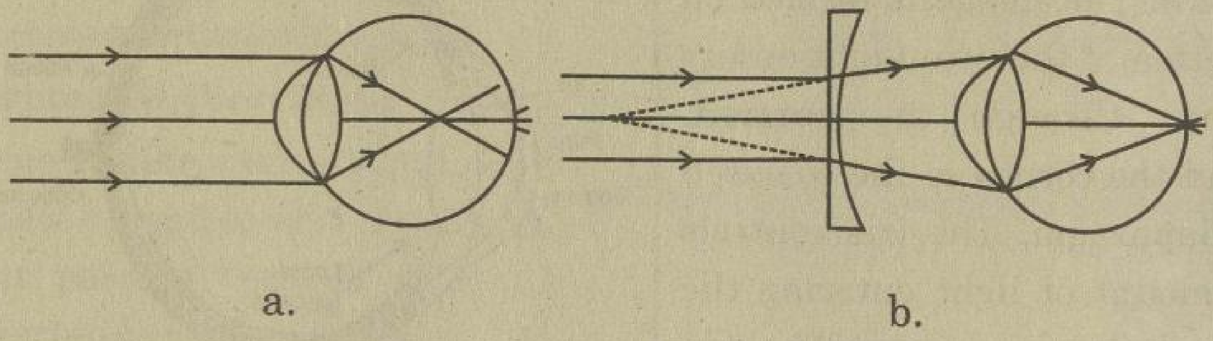


Fig.(14B.24)

Long-Sightedness (hypermetropia)

The defect, in which the eye can see distant objects clearly but nearer objects are not clearly seen, is called long-sightedness. The lens of such an eye is less convergent than a normal eye. The eyeball may be too small. The rays coming from a close object converge towards a point beyond the retina. A convex lens is placed in front of the eye to correct the fault as shown in Fig. (14B. 25).

Long sight

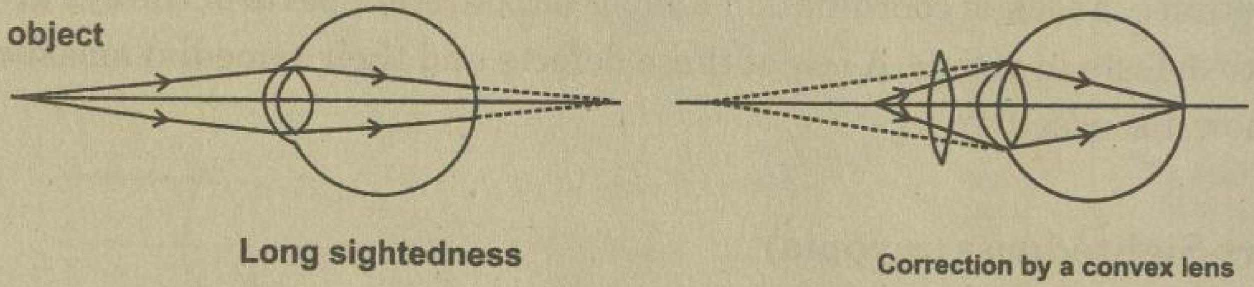


Fig.(14B.25)

SUMMARY

Refraction: When light enters slantly from one medium to another medium, it bends slightly from its original path. Such binding of light is called refraction.

In general, when light enters from a rarer medium to a dense medium, it bends towards the normal. Conversely, when light enters from a denser medium to a rarer medium, it bends away from the normal.

Refraction occurs because the speed of light in the two medial is different.

Laws of Reflection:

(i) The incident ray, the refracted ray and the normal at the point of incidence are all in the same plane.

(ii) The ratio of the sine of the angle of incidence θ_1 to the sine of the angle of refraction θ_2 is constant for a given pair of media. Mathematically

$$\frac{\sin\theta_1}{\sin\theta_2} = n$$

where n is a constants for a given pair of media.

Refractive Index: The refractive index of a medium relative to air is defined as

$$n = \frac{\text{Speed of light in vaccum}}{\text{Speed of light in medium}}$$

Critical Angle : That angle of incidence in the optically rarer medium for which the corresponding angle of refraction in the denser medium is 90° is called the critical angle.

Total Internal Reflection: When the angle of incidence in the denser medium becomes greater than the critical angle θ_c, there is no refracted beam. All the rays are internally reflected back in the optically denser medium. Such a reflection is called total internal reflection.

Prism: A prism is a transparent refracting body, which is bounded by three rectangular and two triangular surfaces. (see figh:14B.4)

Lenses: Lenses are bodies of transparent material shaped so to converge or to diverge a beam of light. Simple lenses are bounded by faces, which are small sections of spheres. Two main types of lenses are convex lens and concave lens.

A convex lens is thickest through the middle and thinnest at the edges.

A concave lens is thinnest in the middle and thickest at the edges.

Lens Formula: The lens formula is: $\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$ where p and q is respectively the distances of the object and the image from the lens. Magnification of an image formed by a lens is: $M = \frac{A'B'}{AB} = \frac{q}{p}$
Power of lens: The reciprocal of the focal length f of lens is defined as the power of the lens, where f is expressed in metres. **Short Sightedness :** The defect in which an eye can see near objects clearly but distant objects are not clear is called shot-sightedness.

Long sightedness: The defect, in which the eye can see distant objects clearly but near objects are not clearly seen, is called long-sightedness

OBJECTIVE QUESTION

I. Fill in the blanks with correct word:

i. To form a real image, _______ lens is used. **[convex ,concave]**

ii. In far-sightedness, the image is found _____ the retina. **[in front of, beyond]**

iii. Rainbow is formed due to _______. **[total internal reflection, regular reflection]**

vi. Image formed by a concave lens is always ______ **[real, virtual]**

v. The image of an object placed within the focal length of a convex lens is __________________. **[real, virtual]**

2. Fill in the blank with correct words.

i. The ray going towards the interface of two media is called ________ ray.

ii. The ray entering from one medium to another medium is called _______ ray.

iii. The angle of refraction in a rarer medium is _______ the angle of incidence in the denser medium.

iv. The incident ray, the refracted ray and the normal to the interface at the point of incidence lie in the same _______.

v. The angle between the refracted ray and the normal to the interface of two media is called angle ______.

vi. The ratio of the sine of angle of incidence in air to the sine of the angle of refraction in glass is called the ______ of glass.

vii. The line joining the two centers of curvatures of a lens is called ______.

viii. The maximum angle of incidence in a denser medium for which there is refraction in a rarer medium is called ______.

ix. Light rays incident at an angle greater than the critical angle at the interface of two different media will be ______ internally.

x. The plane surface of the prism opposite to the angle of the prism is called ______ of the prism.

xi. The smallest angle of deviation of a ray of light caused by a prism is known as the ______.

xii. The transparent medium bounded by two spherical surfaces is called ______.

xiii. The point where parallel rays, meet after refraction through a lens is called ____________.

xiv. The distance of the focus from the optical centre of a lens is called ______

xv. The ratio of the size of the image to the size of the object is called ______.

xvi. The reciprocal of the focal length of a lens expressed in metres is called the ______ of the lens.

xvii. The unit of the power of a lens is ______

xviii. The smallest distance of an object from the eye from where the object can be clearly seen is called the least distance of ______

xix. A convex lens is also called a ______ glass.

3. SHORT ANSWER QUESTION

i. What is meant by refraction of light?

ii. State the laws of refraction of light

iii. Define refractive index. How is it related to velocity of light in a pair of media?

iv. What type of lens is used to correct for long-sightedness.

v. What is the condition on angle of incidence for total internal reflection?

vi. Which lens is of high optical power: the one of short focal length or the one of long focal length?

vii. How is a totally reflecting prism used to turn a beam of light by 90°.

viii. Define the following terms:

(a) Optical centre (b) Principal axis (c) Aperture of a lens

(d) Principal focus

4. COMPREHENSIVE QUESTIONS

i Explain refraction of light. State the laws of refraction. Support your answer with clear diagram.

ii. Define refractive index? How is it related to Snell's law as well as the velocity of light in a pair of transparent media? How would you determine the refractive index of water by finding the real and apparent depths of water in a container?

iii. Explain total internal reflection of light. What are the conditions for total internal reflection? Mention some practical uses of total internal reflection.

iv. Define the critical angle for total internal reflection. What is the relationship between the critical angle and the angle of refraction?

v. What is meant by an optical prism? How does a prism disperse white light into coloured lights? Explain by drawing diagram.

vi. What are optical fibres? On what principal do they operate? Explain a few of its uses.

vii. How is rainbow formed? Write the constituent colours in an order. Explain the difference between primary rainbow and secondary rainbow.

viii. What is meant by a lens? Explain the main types and sub-types of lens. Give the chief optical properties of the each main kind of lenses.

ix. Derive the thin lens formula for a convex lens.
Write down the sign convention for the distances of the object, image and the focus from the lens.

x. Explain with the help of diagram the changes that occur in the image when the object is brought closer to the lens. Consider the cases when the object is at
(a) 2f (b) between 2f and f(c) between f and the lens

xi.. Explain the main defects in lenses. How can each defect be corrected?

xii. What are the chief defects of vision? How can each defected be corrected? Give diagrams.

NUMERICAL PROBLEMS

1. The refractive index of certain glass is 1.4. What will be the speed of light in the glass **[2.1 10^{8} ms^{-1}]**

2. The velocity of light in air is 3×10^{8} ms^{-1}, whereas the velocity in a denser medium is (2×10^{8} m s^{-1}). Find the refractive index of the denser medium. **[1.5]**

3. An object is placed in front of a convex lens. The size of the image formed is the same as the size of the object. Find the distance of the object from the lens. **[= same distance as of the image]**

4. An object of height 5cm is placed in front of a convex lens of focal length 50 cm. The distance of the object from the lens is
(a) 25 cm (b) 75 cm
In each case find the position, nature and size of the image.
[(a). 50cm,virtual erect, 10cm (b) 150cm, real, inverted, 10cm]

5. The distance between an object and a screen is 49cm. By placing a convex lens between them, an image is formed on the screen. The image is six times larger than the object. Find the focal length of the lens. **[6cm]**
6. A small object of size 0.5mm is placed close to a convex lens of focal length 5cm. The virtual image is formed at a distance of 25cm from the lens. Find the magnification and the size of the image. **[6cm , 2.0 mm]**
7. The power of a convex lens is 10 dioptre. At what distance an object be placed so that its image is real and 3 times magnified. **[13.3cm]**
8. An object of height 6cm is placed at a distance of 20cm from a concave lens of focal length 19cm. Find the position, nature and size of the image. **[virtual,6.6cm,2cm]**
9. A pool of water is 4m deep. It is filled with water to a height of 3.5m. Find the apparent depth of water. The refractive index of water is 1.37. **[3.13m]**

Chapter 15

ELECTROSTATICS

In this chapter you will study

- Importance of the study of electricity
- Electric charge: Two kinds of charges; positive and negative
- Atomic and electrical nature of matter
- Electric induction
- Coulomb's law and unit of charge
- Intensity and direction of electric field
- Electric potential and its unit: volt
- Electric capacitor and its capacitance
- Variable and fixed capacitors

15.1 Introduction

The use of electricity has become essential in all walks of our present day life. Using electricity lights electric bulbs and fluorescent tubes. Radio, tape-recorder and calculators etc are run by means of electric cells. Battery is required for the operation of telegraph, telephone and wireless system. Electric fan, electric iron, refrigerator, washing machine, photo state machine and computers use electricity. If electricity is not available, works will almost stop at home and in schools, offices, hospitals and factories etc. You must have many questions in your mind. Where does the electricity come from and where does it go. How does electricity make appliances work? What are the possible dangers in the use of electricity? To find answers to these types of questions, it is necessary to study electricity. In fact, electricity is a branch of physics that has two sub-branches: Static electricity and Current electricity. After developing a few basic concepts, we shall study in this chapter the branch of static electricity, which is also called electrostatics.

15.2 Electric Charge

Electric charge is basic fact. You can understand the existence and the nature of charge by performing the following simple experiments

Experiment 1: Rub a glass rod with a silk cloth. Observe that the glass rod now attracts small pieces of paper, leaves and dust particles. Similarly, the silk cloth also attracts small light objects towards itself. Suspend the rubbed glass rod and the silk cloth by means of threads as shown in Fig. (15.1). You will observe that the glass rod and the silk cloth attract each other. Prior to the process of rubbing neither the glass rod nor the silk cloth had the above mentioned attraction properties.

Experiment 2: Rub a hard rubber rod with a woolen cloth. Observe that the rod as well the cloth attract small light objects towards themselves. The rod and the cloth also attract each other. Prior to rubbing they were not attracting each other.

What results can you derive from the above experiments?

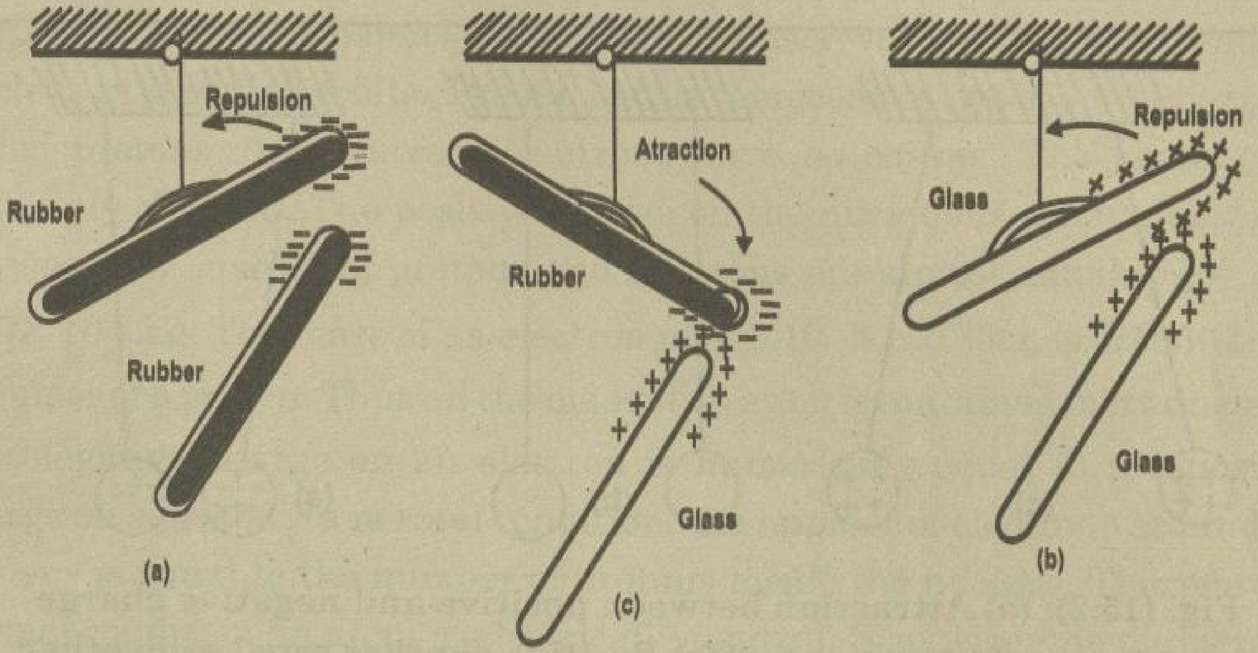
Force is required for the attraction of small light objects towards a rubbed cloth or rod. Similarly, mutual force exists between the rubbed rod and the rubbed cloth. This force cannot be the gravitational force because this force was there before the rubbing process and is not enough to produce an observable attraction. The required force, which becomes observable after rubbing the objects, is, in fact, electrical in nature. Further aspects of this force will now be investigated.

Experiment 3: Suspend a glass rod A by means of a thread and charge it by rubbing with a silk cloth. Similarly, charge another glass rod B and bring it close to the rod A, Fig (15.1a). You will see that the charged glass rods repel each other. Repeat the same kind of experiment with rubber rods rubbed with woolen cloth, Fig. (15.1b). The charged rubber rods repel each other.

Now bring the charged glass rod near the charged rubber rod. The two rods attract each other, Fig. (15.1 c). We conclude from these experiments that

i. There are two kinds of charges. The charge on the glass rod is different than the charge on the rubber rod.

ii. Similar charges repel each other and opposite charges attract each other.



(c) Unlike charges attract each other

(a,b) Like charges repel each other

Fig. (15.1)

You can find from similar further experiments that electrical effects are not limited only to glass-silk or rubber-wool system. In fact, any object can be charged to some extent by rubbing it with another suitable object. One of the objects is charge with one kind of charge and the other one is charged oppositely. One kind of charge is always similar to the charge on the glass rod and the other kind is always similar to the charge on the rubber rod. By convention, the charge on the rubbed glass is considered positive and the charge on the rubbed rubber is considered negative.

Positive charges repel each other. Negative charges also repel each other. But positive and negative charges attract each other.

Experiment 4: Suspend two small pith balls from a fixed support by means of threads as shown in Fig. (15.2). Balls will hang with the threads vertical and parallel to each other. Touch each pith ball for a short time with a positively charged glass rod. On leaving the ball free, you will see that the balls repel each other, Fig. (15.2). In fact, in the touching process, some charge has been transferred from the glass rod to the pith balls. On acquiring charge, the pith balls repel each other.

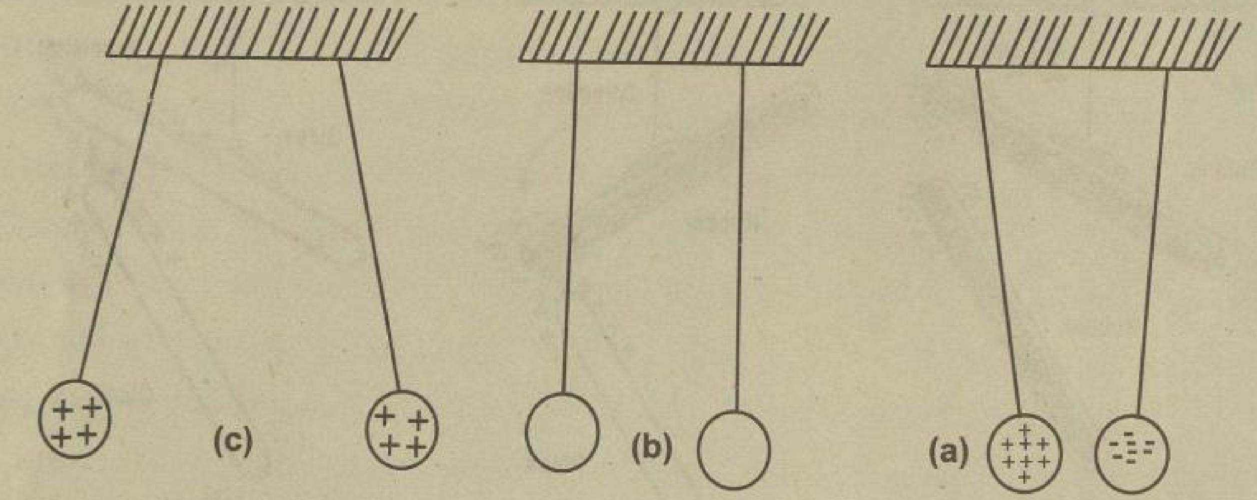


Fig. (15.2): (a) Attraction between positive and negative charge (b) Neutral ball (c) Positive charges repel each other

Now touch one ball with positively charge glass rod and the other with negatively charged rubber rod. You will observe that the suspended balls attract each other, Fig. (15.2c). In this activity, one ball has acquired positive charge from the positively charged glass rod and the other has acquired negative charge from the negatively charged rubber rod.

These experiments show that charge, whether on glass, rubber or any other object, can be transferred to another body by touching it with the body.

15.3 Electrical Nature of Matter

It is a universal fact that all bodies can be charged. Thus electric charge is a general property of matter. In general, a piece of matter is commonly electrically neutral. Thus equal amounts of positive and negative charges are present in a neutral matter. The various electrical effects can be explained in terms of the charges contained in matter. A few basic concepts of the electrical nature of matter are now presented.

The structure of Atom

You know that all material objects are composed of very small particles called atoms. An atom consists of a central positively charged nucleus. Negatively charged particles called electrons revolve rapidly around the nucleus in specified orbits. The nucleus is composed of two kinds of particles called protons and neutron. Neutrons have no charge. The protons are positively charged. The positive charge on the nucleus is solely due to the protons. The masses of protons and neutrons are almost equal: $m_p = m_n = 1.67 \times 10^{-27}$ kg. The mass of an electron $m_e = 9.10 \times 10^{-31}$ kg, is 1/1836 times the mass of a proton. Thus all the mass of an atom is contained in its nucleus. The negative charge on an electron is numerically equal to the positive charge on a proton. In normal condition, the number of electrons around the nucleus is equal to the number of protons inside the nucleus. Therefore, in normal condition an atom is electrically neutral. Size-wise, the diameter of an atom is ten thousand times the diameter of its nucleus.

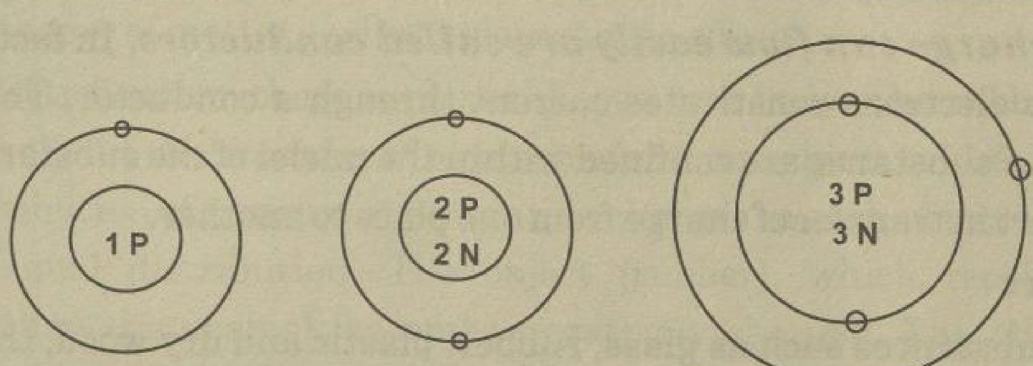


Fig. (15.3) Models of Hydrogen, Helium and Lithium atoms

The models of Hydrogen, Helium and Lithium atoms are shown in Fig. (15.3). Number of protons as well as the number of orbital electrons in each atom is shown in the figure.

The atomic structure of heavier atoms is more complicated. However, the basic principle is the same as shown for lighter atoms. As the number of electrons in an atom increases, they cannot be accommodated in the same orbit. The number of orbits also increases. Electrons move in their specific orbits around the nucleus. The maximum number of electrons that can be accommodated in the first or innermost orbit is two. The second orbit can contain a maximum of 8 electrons and the third orbit can have a maximum of 18 electrons. The characteristics of one kind of atom are different from another kind of atom. The various kinds of atoms are different because they contain different number particles. The number of electrons in the outermost orbit determines the chemical properties of an atom and these electrons are called ***valence electrons***.

15.4 Conductors and Insulators

Conductors

The valence electrons of the atoms of some substances such as solid copper, iron, aluminium and other metallic substances are not bound to any particular mother atom. Such electrons can move freely within the solid. They are called ***free electrons***. Substances that have large number of free electrons can easily conduct electric current. ***Substances through which electric charge can flow easily are called conductors.*** In fact, the flow of the free electrons constitutes current through a conductor. The protons present in a substance are confined within the nuclei of the substance and do no take part in transfer of charge from one place to another.

Insulators

In some substances such as glass, rubber, plastic and dry wood, the valence electrons are very tightly bound. They have very little freedom to move. Therefore, electric current cannot flow easily through such materials. ***Substances through which electric current cannot pass easily are called insulators.*** On a charged insulator, the charge is locally confined and cannot spread over the surface of the insulator. In the use of electricity, the surface of a conductor is covered with insulation.

A substance is neither a perfect conductor nor a perfect insulator. The number of free electrons in the substance determines the conductivity of a substance. Air is an insulating medium but under intense electric forces, it can temporarily become a conductor. During lightening strikes, the air between the ground and the charged clouds become conductor and allows current to flow. Pure water is insulator but the presence of small amount of salts makes it conductor. Human body is somewhat conductor. Earth is conductor and is a big reservoir for receiving or supplying electrons to other bodies. If we want to discharge a charged body, we connect the body by means of a conducting wire to the earth, that is, we earth the charged body. Depending upon the nature of the charge on the body, electrons flow from the earth to the charged body or vice-versa to neutralize the charge on the body. In order to avoid electric shocks, the metallic parts of electric instruments and appliances are usually earthed

15.5 Electrification by Contact

You have observed that in the process of rubbing glass with silk or rubber with wool or rubbing any two suitable objects, each of the two objects is electrified. Besides this process you also studied that a neutral body receives charge by bringing it in contact, for a while, with another charged body. The electrical theory of matter easily explains these effects.

Prior to electrification, there is no net charge on a body. The rubbing of two objects results in the transfer of electrons from one object to the other. The equal distribution of positive and negative charges in each object is changed to an unequal distribution. The object (rubber), which receives more electrons than the normal, becomes negatively charged. The other object (wool) has deficit of electrons and excess of protons than the normal and becomes positively charged. The excess positive charge on the wool is exactly equal to the excess negative charge on the rubber. You may note carefully that the transfer of charge takes place solely through electrons. The protons remain confined to the nuclei of the substance and do not take part in the transfer of charge.

15.6 Electrostatic Induction

There are two simple methods of charging a neutral body positively or negatively.

i. Electrification by contact

2. By induction

The first method has been described in connection with charging a glass or rubber rod, pith ball and a conductor. We shall now describe the second method of electrification by induction.

When a charged body is brought near to, and not in contact with, a neutral body, then the negative and positive charges of the neutral body rearrange themselves on the surface as well as in the interior of the body. This effect is called electrostatic induction. The rearranged distribution of charge persists as long as the charged body remains close to the neutral body. By removing the charge inducing body, the neutral body regains its original state. Let us find out the changes that are brought about by electrostatic induction in the charge distribution of conductors as well as insulators.

Charging an Insulator by Induction:

Fig. (15.4) shows that a negatively charged comb is brought close to a neutral insulator. The electrons of the atoms in the insulator tend to be away from the comb. However, the electrons are tightly bound to the mother nuclei and cannot be translated from one place to another. In the present situation, the electrons are at least, pushed locally away from the comb. The positive nuclei remain fixed at their original positions. The atoms of the insulators adopt themselves into plus-minus (+, -) poles of charges. We say that the insulator has been polarized by the presence of the charged rod.

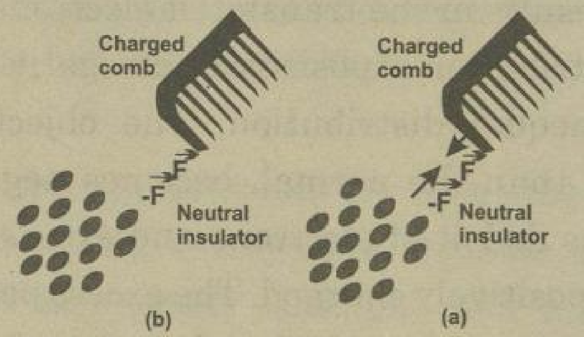


Fig.(15.4) A charged comb polarizes a neutral object and then pulls it towards itself.

The net result of the polarization of the insulator is that a layer of positive charge appears on the end of the insulator nearest to the rod. A layer of negative charge accumulates on the furthest surface of the insulator. The positive end, being closer, is attracted more strongly than the repulsion of the negative end of the insulator. This is how a charged body attracts a nearby insulator body by the process of electrostatic induction. This is how light pieces of paper are attracted towards a charged rod.

You can repeat the above activity by bringing a positively charged glass rod towards a neutral insulator. Electrostatic induction will polarize the insulator. The end closest to the rod will be negatively charged and the further end will be positively charged. The net result is the over all attraction of the neutral insulator towards the charge rod.

Charging a Conductor by Induction:

Now let us investigate the case of induced charges in a conductor. Fix a metallic sphere on an insulating wooden stand. Bring a positively charged rod near the sphere, Fig. (15.5). The free electrons in the metallic sphere will move towards the charged rod. Consequently, negative charge will accumulate on the surface of the sphere. Due to electrostatic induction, the earlier charge distribution on the surface of the sphere changes into a new charge distribution. Keeping the rod in its place, earth the conductor by

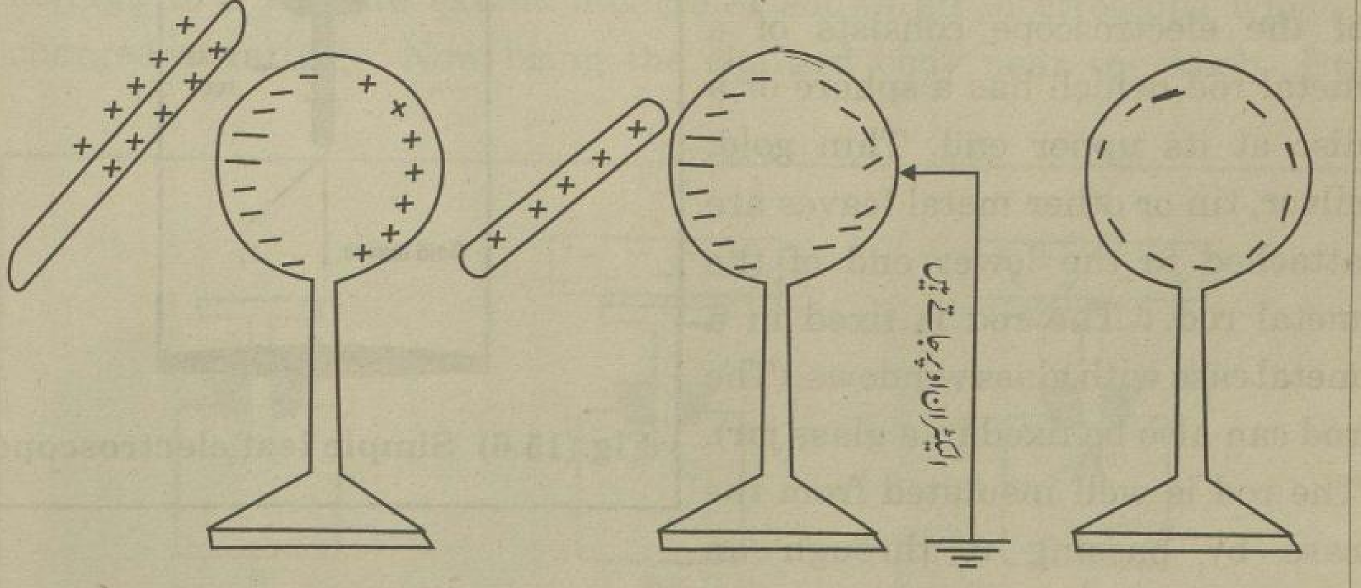


Fig. (5.5): Electrification of an insulated metallic sphere by electrostatic induction

touching it for a short time with your finger. In this short time, electrons will move from the earth towards the conductor. By removing the rod, the conductor is negatively charged. Due to mutual repulsion, the electrons spread uniformly on the surface of the metallic sphere. ***The method of charging a conductor in this manner is called charging by induction.*** A freely suspended charged pith ball can find out the presence of negative charge on the sphere.

Repeat the above activity by bringing a negatively charged rod near an insulated neutral metallic sphere. Touch the sphere while keeping the rod in its place. Some electrons will move from the sphere towards the earth. On removing the rod, the sphere will be left with deficit of electrons and will be positively charged. The deficit of electrons will spread uniformly over the surface of the sphere. The sphere will be uniformly charged.

15.7 Leaf Electroscope

An electroscope is a simple and sensitive instrument for detecting and testing the positive or negative nature of electric charges. One form of the electroscope consists of a metal rod, which has a sphere or a disc at its upper end. Thin gold, silver, tin or other metal leaves are attached to the lower end of the metal rod. The rod is fixed in a metal case with glass windows. (The rod can also be fixed in a glass jar). The rod is well insulated from the case by passing it through an insulating plug, Fig. (15.6).

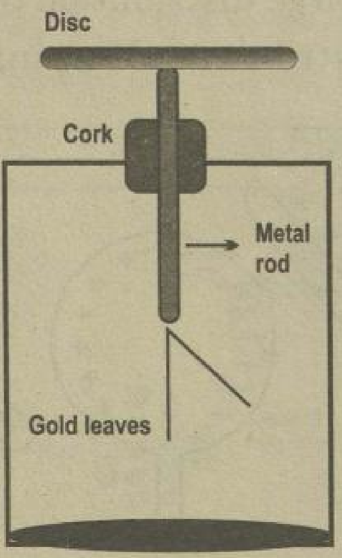


Fig.(15.6) Simple leaf electroscope

Charging an Electroscope

The leaf electroscope can be charged positively or negatively by conduction (the contact method of electrification) or by electrostatic induction.

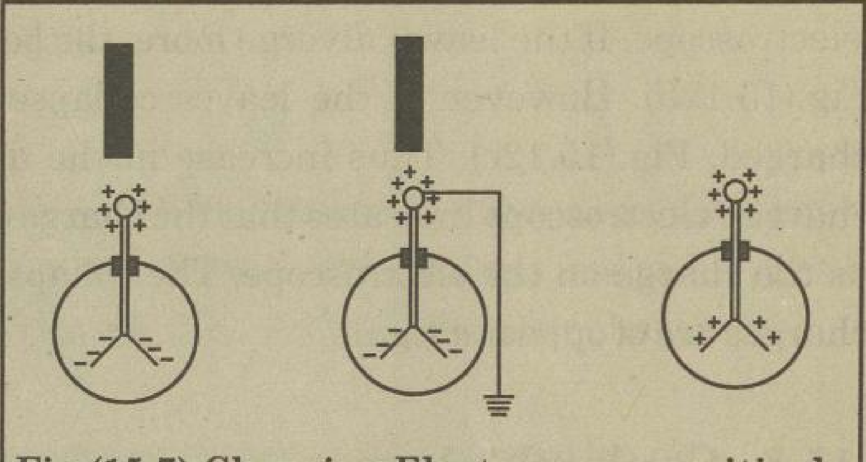


Fig.(15.7) Charging Electroscope positively

If a positively charged body is brought in contact with the knob of an electroscope, then electrons will be transferred from the leaves andthe metal rod to the body. The leaves acquire positive charge. Similarly, the leaves are charged negatively by touching the knob with a negatively charged body. In both the cases, the leaves are similarly charged and cause divergence of the leaves.

The electroscope can be charged by induction. Bring a negatively charged body near the knob of the electroscope. Earth the knob of the electroscope and then remove the charged body. The leaves are left with positive charge and remain diverged, Fig.(15.7).

Testing for Positive or Negative Charge on a Body

Charge an electroscope either positively or negatively. The leaves will diverge to a definite extent. Fig.(15.8) shows an electroscope which is charged negatively. Now bring the charged body near the knob of the

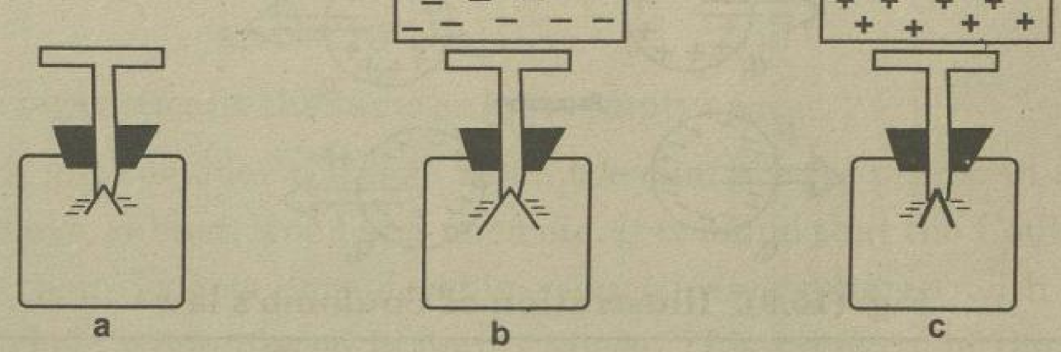


Fig.(15.8) Testing the sign of charge

electroscope. If the leaves diverge more, the body will have negative charge, Fig.(15.12b). However, if the leaves collapse, the body will be positively charged, Fig.(15.12c). Thus increase in the divergence of the leaves of a charged electroscope indicates that the charge on the body is of the same sign as the charge on the electroscope. The collapse of the leaves indicates that charges are of opposite sign.

15.8. Coulomb's Law

Experiments show that there exists a force of attraction or repulsion between charged bodies. Like charges repel and unlike charges attract each other. This electric force depends on the distance between the charges and the magnitudes of the charges. In 1785, the French physicist Coulomb measured the force between charged spheres for various distances between them. On the basis of his observations, Coulomb formulated a law, which is found valid till today. Coulomb's law states that ***the force of attraction or repulsion between two charges q_1 and q_2 is directly proportional to the product of the charges and inversely proportional to the square of the distance between them.*** Mathematically

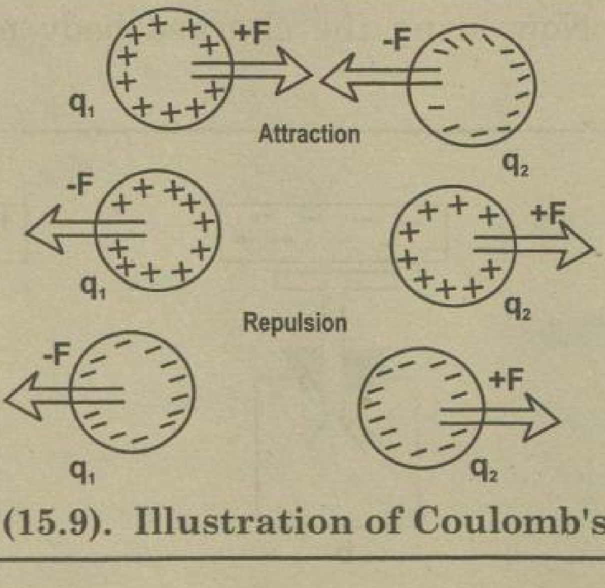


Fig. (15.9). Illustration of Coulomb's law

$$F \propto q_1 q_2 \qquad \text{(i)}$$

$$F \propto \frac{1}{r^2} \qquad \text{(ii)}$$

Combining Eqs.(i) and (ii), we get

$$F = k\frac{q_1q_2}{r^2} \qquad (15.1)$$

where k is a constant of proportionality. The value of k depends on the nature of the medium between the charges and the system of units in which F, r and q are measured. In SI units and for vacuum or air between the charges,

$$k = 9\ \ 10^{9}\,\mathrm{N\,m^{2}}\ \ \mathrm{C}^{-2}$$

Thus Coulomb's law for charges placed in vacuum is thus written as

$$F = k_o\frac{q_1q_2}{r^2} \qquad (15.2)$$

Considering coulomb as a derived unit, we can, however, define it from Coulomb's law.

One coulomb is the quantity of charge which when placed 1 meter apart from an equal and similar charge in vacuum repels it with a force 9 × 10^{9} newton. Numerically, one coulomb is equal to the charge on 6.24×10^{18} electrons. The commonly used sub unit of coulomb is micro coulomb:[micro(μ) = 10^{-6}]

Coulomb's Law in Dielectrics

The force between charges depends on the medium between the charges and this dependence is contained in the value of k in Coulomb's law (15.1):

$$F = k\ \frac{q_1q_2}{r^2} \qquad \text{(i)}$$

For empty space, k is found to be

$$k_o = 9\times10^{9}\,\mathrm{Nm^{2}\,C^{-2}} \qquad \text{(ii)}$$

For air, k is practically the same as k_o for empty space.

Instead of air, consider the case when the charges are placed in a medium such as glass, rubber, wood and mica etc. It is found that the Coulomb force between them is now considerably reduced as compared with the force between them when placed in empty space. This property of the dielectric medium around the charges that affects the force between them is called ***permitivity***. For charges placed in a dielectric medium, Coulomb's law takes the form

$$F = \frac{k\, q_1 q_2}{\varepsilon\, r^2}$$

Where ε is the permittivity of the dielectric medium relative to the permittivity ε_o for free space.

It should also be realized that Coulomb's force is strictly valid for point charges. However, if the size of the charge bodies is very small compared with the distance between them, then Coulomb's can be considered valid. Moreover, if the charge is distributed uniformly over the surface of a sphere, then it can be considered as a point charge placed at the center of the sphere

Example 15.1: A charge of 25 μC is placed in air at a distance of 0.5m from a charge (-50 μC). Find the force on each charge.

Solution:

The data given in the problem is :

$q_1 = 25\ \mu C$

$q_2 = -50\ \mu C$

$R = 0.5\ m$

According to Coulomb's law

$$F = k\ \frac{q_1 q_2}{r^2}$$

Putting the given values in the above equation

$$F = 9 \times 10^9\ \frac{Nm^2}{C^2}\ \frac{25{\times}10^6 C \times (-50)\ 10^{-6}\ C}{(0.5m)^2}$$

Using calculator,

$F = -45N$

The negative shows that the force on each charge is attractive. Magnitude of the charge is 45N.

Example 15.2: Hydrogen atom is composed of one proton and one electron. The distance between these particles is 5.3×10^{-11}m. The space between them is free space. Find the electrical force between the electron and proton.

Solution:

Charge on proton $e^{+} = 1.6\times10^{-19}\,C$

Charge on electron $e^{-} = -1.6\times10^{-19}\,C$

Distance between the charges $= r = 5.3\times10^{-11}\,m$

According to Coulomb's law, the electrical force between the particles is

$$F_e = k\frac{e^{+}e^{-}}{r^{2}}$$

$$= 9\times10^{9}\,\frac{N-m^{2}}{C^{2}}\,\frac{1.6\times10^{-19}\,C(-1.60\times10^{-19}C)}{(5.3\times10^{-11}m)^{2}}$$

$$F_e = -8.2\times10^{-8}\,N \qquad \text{(i)}$$

15.9. Electric Field

The region in the vicinity of a charged body possesses special properties because of the presence of charge. For example, another charge brought into this region will experience an electric force. Such a region of space is known as electric field. *An electric field is defined as any region in which an electric test charge, brought into the region, would experience an electric force.* It is a vector field, i.e. at each point of the region there is a directed electric force on the test charge. The test charge itself is chosen positive and so small that its presence does not distort the original field.

Electric Field Intensity

The intensity (or strength) of an electric field at any point is defined as the force per unit positive test charge q placed at that point.

Mathematically

$$\vec{E} = \frac{\vec{F}}{+q} \qquad (15.9)$$

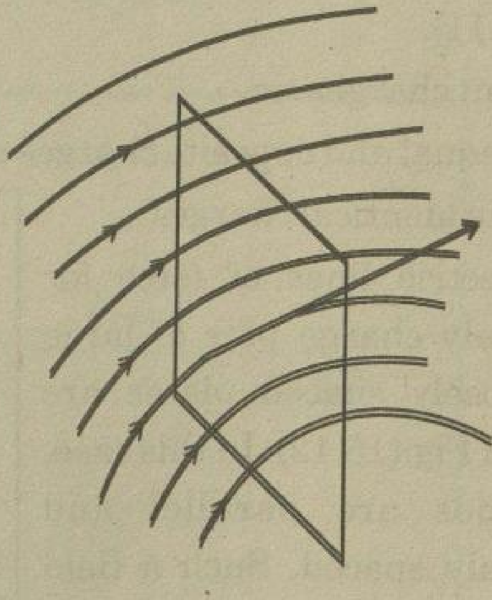


Fig.(15.10 Electric field intensity

Being a force, the field intensity is a vector quantity. Its direction at any point is the same in which the test charge will move. The unit of electric intensity is Newton/coulomb [NC^{-1}]

Electric Lines of Force

It is convenient to represent the electric field in the vicinity of charged bodies by drawing lines of force. An electric line of force is, in general, a curved line in which the test charge would move. The local direction of the line represents the direction of the field. The intensity E of the field is represented by the number of lines of force per unit area normal to the field, Fig.(15.11).

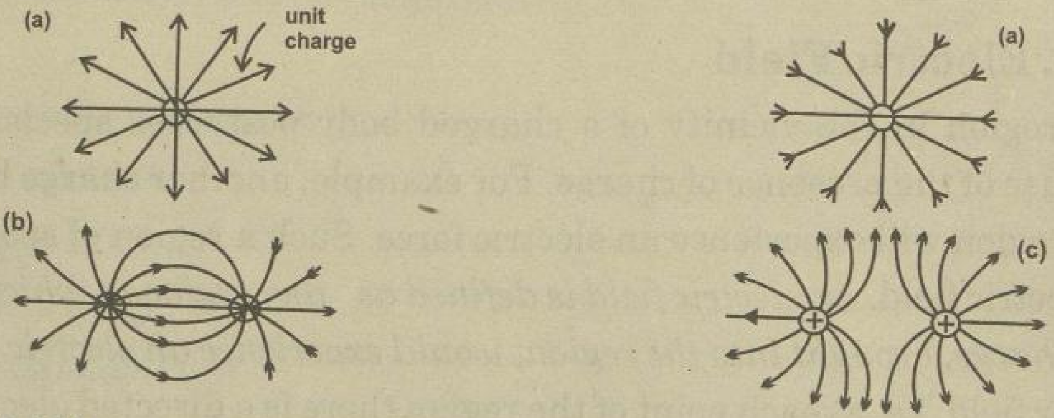


Fig.(15.11)

The lines of force diagrams for the following charges are shown in Fig.(15.11).

(a) point charges ± q,

(b) two equal and opposite charges and

(c) two identical charges

The electric lines of force for oppositely charge pair of large and closely spaced plates are given in Fig.(15.12). In this case, the lines are parallel and uniformly spaced. Such a field

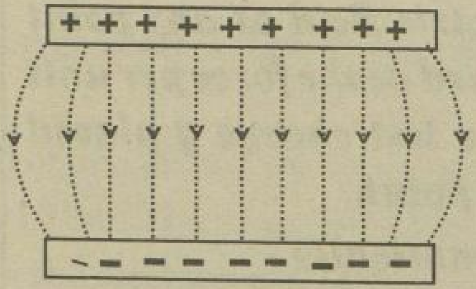


Fig. (15.12) Uniform electric field between a pair of large charged plates

of uniformly spaced parallel lines is called a ***uniform electric field.***

15.10. Electrostatic Potential

The concept of electrostatic potential is analogous to the concept of gravitational potential. Work has to be done in raising a body against the gravitational pull of the earth. This work is stored as increase in the gravitational potential energy of the body. Now if the body is released from this height, it falls towards the earth. This implies that a body moves from higher potential towards lower potential.

There is an electric field around a charge. The electric force on a charge q at a place of intensity E is q E. Work has to be done in moving a charge against the electric field from one point to another in the field. This work done W on the charge appears as an increase in its electric potential energy. Thus change in electric potential energy is equal to W.

Potential Difference (PD)

The work done in moving a unit positive charge from point A to another B against the electric field is defined as the electric potential difference between the points A and B.

Symbolically

$$V_B - V_A = \frac{W_{AB}}{q} \qquad (15.10)$$

where V_A and V_B are the potentials at points A and B.

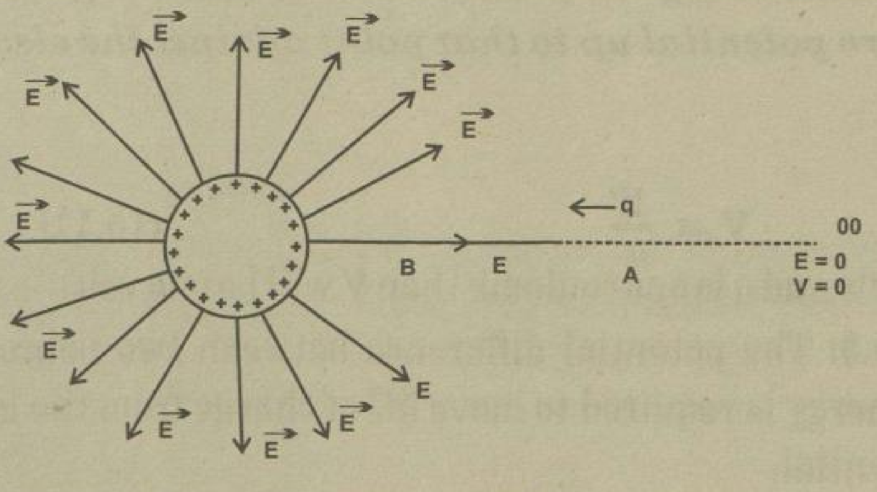


Fig.(15.13). Electrostatic potential. Work is required to move a charge q against E.

If W_{AB} is the work done by an external agent, then $V_B > V_A$. However if W_{AB} is done by th electric field then $V_B < V_A$, i.e. B is at lower potential than A.

In Eq (15.13), if W_{AB} is one joule and q is one coulomb, then

$$V_B - V_A = \frac{1\,joule}{1\,coulomb}$$

This difference of potential is called one volt.

Unit of Potential: ***If one joule of work is required to move a unit positive charge from on point to another point in an electric field, then the electric potential difference between these two point is defined as one volt.***

$$Volt = \frac{joule}{coulomb}$$

As potential difference is expressed in volts, it is often termed as voltage.

Basically, potential difference is always measured between two points. However, the concept of potential at a point in an electric field is also useful. The potential at a point B in a field can be specified if we take a suitable point A as the zero of potential. In electrostatics, the zero of potential is usually chosen to be at infinity. In many situations, the earth being a conductor and a big reservoir is chosen as zero of potential. In radio or television receiver or in wiring of a car, the chassis is regarded as being at zero potential.

The potential V at a point P in an electric field is defined as the work per unit positive charge required to bring the charge from the point of chosen zero potential up to that point against the electrical forces of the field.

$$V = \frac{W}{q} \qquad (15.11)$$

If W is one joule and q is one coulomb then V will be one volt.

Example 15.3: The potential difference between two points is 220 volts. How much energy is required to move 5C of charge from the lower potential to higher potential.

Solution:

$$\text{Potential difference} = V_A - V_B = \frac{W}{q}$$

$$W = q(V_A - V_B)$$

$$W = 5C \times 220\ V = 1100\ \text{joule.}$$

Thus the energy required = 1100J.

Example 15.4: In Fig. (15.14), the plates are 6 cm apart and air is the medium between them. The PD between the plates is 12 Volt. Find the intensity of the field between the plates.

Solution: The field is uniform and

$E = ?$

PD = 12 volt

The distance between the plates:

$d = 6cm = 0.06m$

The work required to displace q coulomb of charge through distance d is

$W = Fd$

$W = qEd \qquad (F = qE)$

$$E = \frac{W}{qd} = \frac{12\ Volt}{1C \times 0.06m}$$

$$E = 220\ N\ C^{-1}$$

In the above calculations we have the conversion relations: J = Nm and Volt = J/C

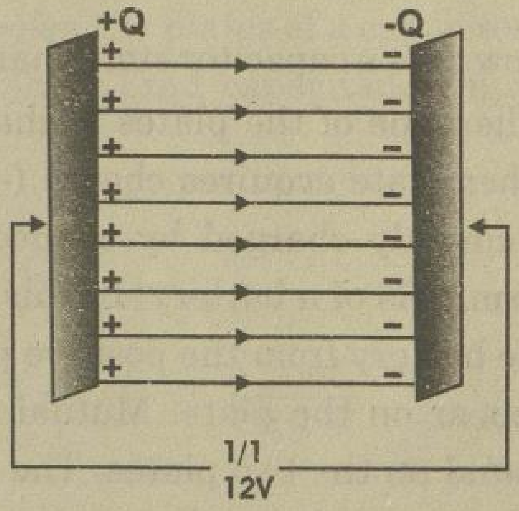


Fig. (15.14) Uniform field between the plates

15.11 Capacitor

Any device which can store electric charge is called capacitor. A simple capacitor consists of two parallel metal plates separated by some insulator like air, paper, mica oil etc.

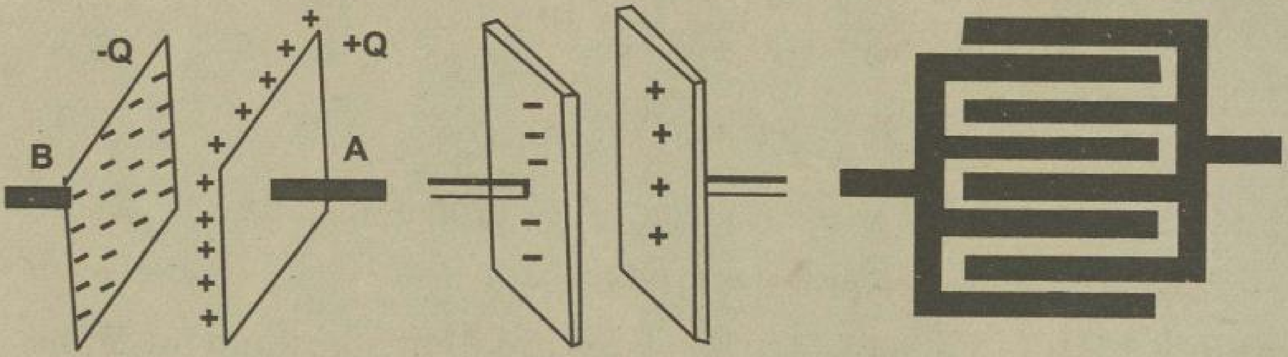


Fig. (15.15) Parallel plate capacitor

How does a capacitor store charge?

When one of the plates is charged Q, then by electrostatic induction, the other plate acquires charge (-Q) as shown in Fig. (15.15).The capacitor is commonly charged by connecting its plates for a while to the opposite terminals of a battery. In this way some electrons are transferred through the battery from the positive plate to the negative plate. Charge +Q and Q appear on the plate. Mutual attraction between the charges keeps them bound on the two plates. The charge remains stored in the capacitor even after removal of the battery.

Capacitance of a Capacitor

The capacity of a capacitor t store charge is its ***capacitance***. What are those factors, which determine the capacitance? There is an electric field as well as potential difference (pd) between the plates. The positively charged plate is at higher potential than the negatively charged plate. As the charge Q increases, the PD between the plates increases; there is direct relation between the two:

$$Q \propto V$$

$$Q = CV \longrightarrow C = \frac{Q}{V} \qquad (15.12)$$

C is constant and is known as the capacitance of the capacitor. The value of C depends on the area of the plate, the distance between the plate and the insulating material or dielectric between the plates. The larger the plates, the closer the plates and more insulating the medium between them, the higher is the capacitance of the capacitor.

Units of Capacitance:

SI unit of capacitance is called farad, in honour of M. Faraday. Using Eq. (15.12), ***a capacitor has capacitance of one farad for a charge of one coulomb,*** will give the plates a potential difference of one volt. Convenient sub-multiples of farad are:

$$1 \text{ micro-farad} = 1\,\mu f = 10^{-6} \text{ farad}$$

$$1 \text{ micro-micro farad} = 1\,\mu\mu = 1 \text{ pico farad} = 10^{-12} \text{ farad}$$

Example 15.5: The potential difference between the plates of a capacitor is 750 volts. The charge on each plate is 0.006C. Find capacitance of the capacitor.

Solution:

Charge on each plate $= Q = 0.006$ C

Potential difference $= V = 750$ V

Capacitance of the capacitor $= C = \dfrac{Q}{V} = \dfrac{0.006C}{750VG}$

Or $C = 8 \times 10^{-6}$ farad $= 8\mu$f.

15.12 Combinations of Capacitors

There are many situations in electrical circuits where more than one capacitors are used. The capacitors can be combined either in series or in parallel. We wish to find out an *equivalent capacitor* that has the same capacitance as that of the combination of capacitors

Series Combination of Capacitors

Fig.(15.16) shows three capacitors connected in series. They are connected plate to plate. A battery of voltage V is connected between points A and B. The battery supplies +Q charge to the left plate of the capacitor C_1. Due to

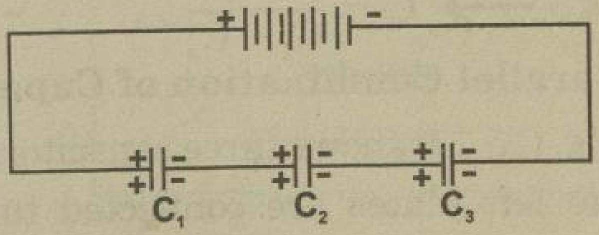


Fig.(15.16) Capacitors in series combination

induction, -Q charge is induced on its right plate. The electrons, which produce the negative charge on C_1 must come from the left plate of C_2 and leave it with charge +Q. This charging process continues to capacitor C_3 as shown in the figure.

Thus, ***when capacitors are charged in series combination, the same charge is stored on each capacitor.***

Let Q be the charge on each capacitor. The potential difference, V must be equal to the sum of potential differences V_1, V_2, V_3 across the capacitors

$$V = V_1 + V_2 + V_3$$

$$= \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$$

Divide both sides by Q

$$\frac{V}{Q} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Let C be the equivalent capacitance of the three capacitances joined in series. Then

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

For n capacitors connected in series

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} \cdots\cdots \frac{1}{C_n}$$

For two capacitors connected in series

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{C_2 + C_1}{C_1 C_2}$$

$$\longrightarrow C = \frac{C_1 C_2}{C_2 + C_1}$$

Parallel Combination of Capacitors

Fig. (15.17) shows three capacitors connected in parallel. In this method, all the left plates are connected to one point and all the right plates are connected to another point. A battery of voltage V is applied between the points A and B. In this combination all the capacitors have the same equal

PD, V across them. The charge Q given at the point A, will be distributed over the capacitors such that

$Q = Q_1 + Q_2 + Q_3$

$Q = C_1V + C_2V + C_3V$

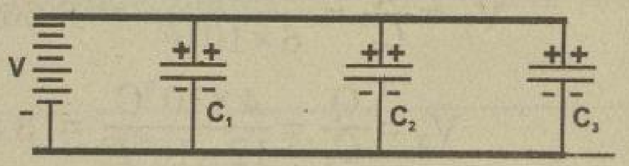


Fig.(15.17 Parallel combination of capacitors

Divide both sides by V

$$\frac{Q}{V} = C_1 + C_2 + C_3$$

Let C be the equivalent of the three capacitances joined in parallel.

Then $\quad C = C_1 + C_2 + C_3$

For n capacitor connected in parallel

$$C = C_1 + C_2 + C_3 \ldots\ldots + C_n$$

Example 15.6: Two capacitors $C_1 = 6\mu$ F and $C_2 = 12\mu$F are connected in series to a voltage source of 1000 V. Calculate the (a) total capacitance, (b) the charge on each capacitor and (c) the potential drop across each capacitor.

Solution: The series combination is shown in Fig.(15.18)

(a) The equivalent capacitance is given by

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{C_1 + C_2}{C_1C_2}$$

$$\longrightarrow \quad C = \frac{C_1C_2}{C_1 + C_2} = \frac{6\times12}{6+12}\,\mu F$$

Note that C is smaller than each of the Given capacitance

b) In series combination the charge on each capacitor is the same

$Q = CV = 4\,\mu F + 1000V = 4\times10^{-6}\,F\times10^{3}\,V$

$Q = 4\times10^{-3}$ coulomb

c) The potential drops across C_1 and C_2 are

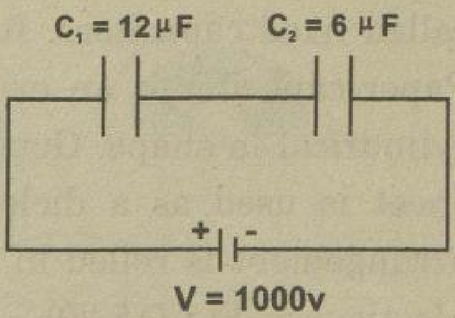


Fig.(15.18)

$$V_1 = \frac{Q}{C_1} = \frac{4\times10^{-3}C}{6\times10^{-6}F} = 6.666\times10^{2}V.$$

$$V_2 = \frac{Q}{C_2} = \frac{4\times10^{-3}C}{12\times10^{-6}F} = 3.333V = 3.333\times10^{2}V.$$

Example 15.7: Two capacitors of 5μF and 10μF are connected in parallel to a 20 V battery. Find

(a) the equivalent capacitance

(b) the charge on each capacitor.

Solution: The parallel combination is shown in Fig. (15.19)

(a) The equivalent capacitance is

$C = C_1 + C_2 = 5\mu F + 10\mu F = 15\mu F$

(b) The charges on C_1 and C_2 are

$Q_1 = C_1V = 5\mu F + 20V = 100\mu C$

$Q_2 = C_2V = 10\,\mu F \times 20V = 200\mu C$

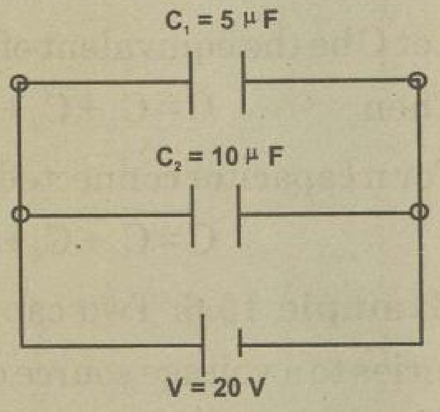


Fig. (15.19)

15.13: Different Types of Capacitors:

Capacitors, in common use, are of various kinds, sizes and shapes. They are all, some modifications of the parallel plate capacitor. They can be classified into fixed capacitors and variable capacitors.

Fixed Capacitors: Those capacitors whose parts are fixed by design are called fixed capacitors. Its capacitance is constant and cannot be varied. Paper capacitor is an example of fixed capacitor. The paper capacitor is cylindrical in shape. Generally an oiled or greased paper or a thin plastic sheet is used as a dielectric between two aluminium foils. The whole arrangement is rolled in the form of a cylinder and is then enclosed in a plastic case, Fig. (15.20)

Mica capacitor is another example of fixed capacitors. In these capacitors, mica is used as dielectric between two metal plates. For sake of safety, they are enclosed in an insulating plastic cover wires attached with plates project out of the case for making electrical connections. If the capacitance is to be increased a large number of plates are piled up, one over the other with layers of dielectric in between. Alternate plates are connected with each other, Fig, (15.20)

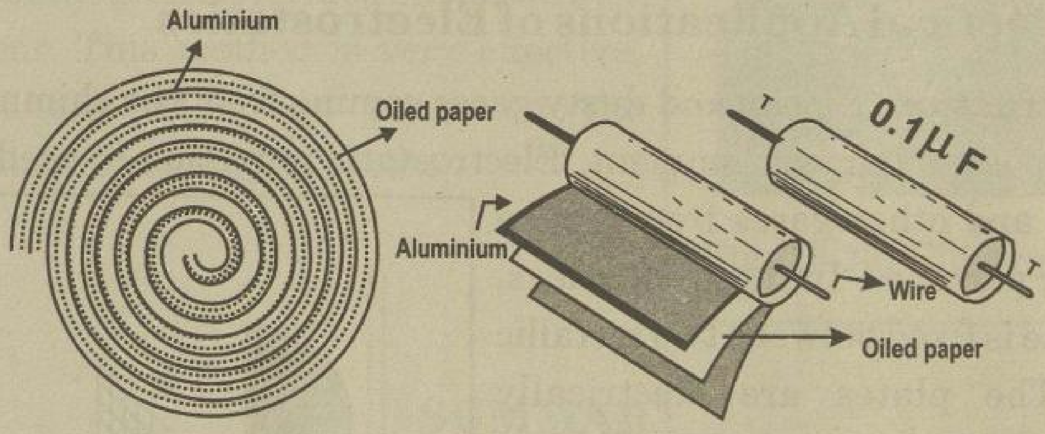


Fig. (15.20): Different types of capacitor

Variable Capacitors: If in a parallel plate capacitor some arrangements made so that the area of the plates facing each other can be changed, then it is called a variable capacitor. It is usually a combination of many capacitors with air as dielectric. It consists of two sets of plates. One set remains static while the second one can rotate so the distance between the plates remains the same and they do not touch each other. The common area of the plates of

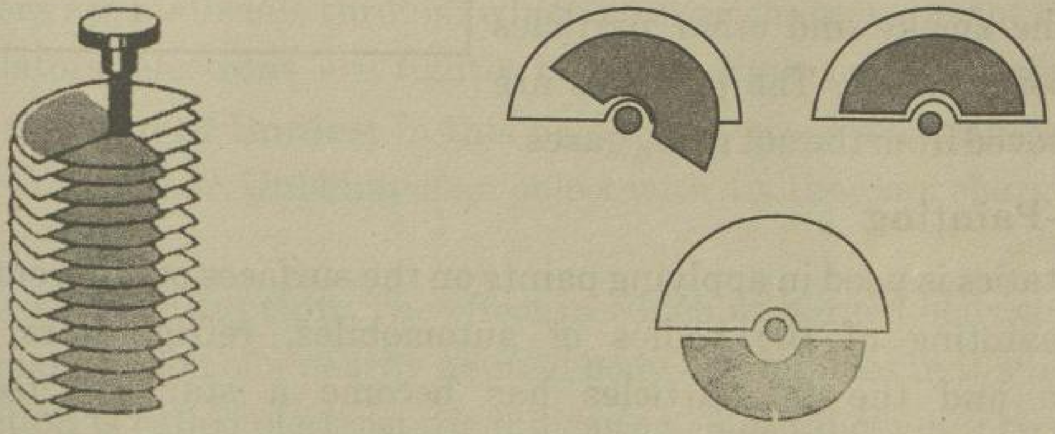


Fig. (15.21). Gang type variable capacitor the two sets which faces each other, determines the value of the capacitance. Thus the capacitance of the capacitor can be increased or decreased by turning the rotatable plates in or out of the space between the static plates; Fig. (15.21). Such capacitors are generally used for tuning in radio sets.

15.14 Practical Applications of Electrostatics

Dust Extraction: Smoky and dusty gases coming from the chimneys of factories pollute our environment. Electrostatic induction is used to clean the air and other gases from smoke and other particles. In these chimneys, wire gauze is fixed between two metallic plates. The plates are electrically earthed and the wire is highly charged with positive charges. The wire gauze induces negative charges on the inner faces of the plates. An intense electric field exists between the gauze and the plates.

When air and other gases exit through the chimney, they acquire positive charge by coming in contact with the wire gauze. Thereby, they are attracted to the metallic plates. On reaching the plates, the smoke and other particles are deposited there. The particles are thus removed from the out going gases.

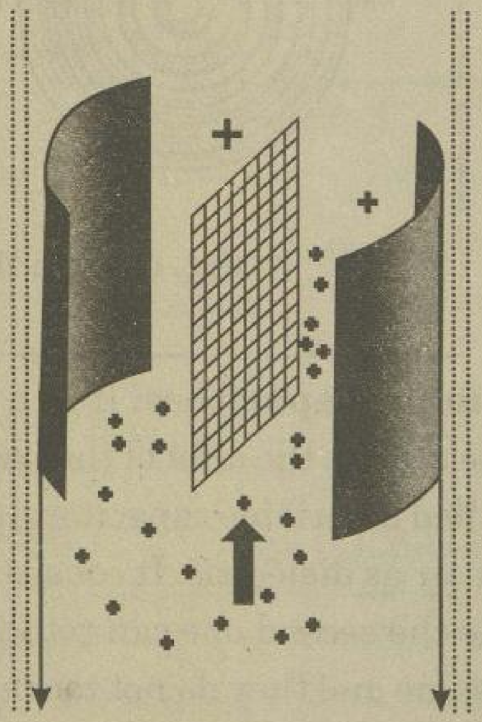


Fig. (15.22)

Electro-Painting

Electrostatics is used in applying paints on the surfaces of different articles. Electro-painting of the bodies of automobiles, refrigerators, metallic furniture and the like articles has become a standard technology. The body of the article, such as a car, is earthed. The particles of the paint emerge out of the nozzle of the spray machine. Due to friction, the emerging paint particles acquire a positive charge. When these positively charged particles reach the electrically grounded body of the car, they are deposited there. A firm coating of the paint is formed on the surface of the car. This method is very effective, efficient and cheap as compared the conventional spraying methods.

Fig.(15.23) Electropainting

SUMMARY

Electric Charge and Atomic Theory: There are two kinds of charges positive and negative. Protons contained in the nucleus of an atom have positive charge and electrons are revolving or clouding in specified orbits around the nucleus carry negative charge. The magnitude of charge on proton and on an electron is the same: i.e 1.60×10^{-19} coulomb.

Valence electrons of an atom are those electrons that are in the outermost orbit.

Conductors and Insulators: Materials through which electric charges flow easily are called conductors. They contain less number of free electrons. Insulators are materials through which electric charges do not flow easily. In insulators, electrons are tightly bound to their positive central cores.

Electrification of Bodies: In this process electrons are transferred from one body to another. Rubbing of an object with another can charge both the bodies.

Electrostatic Induction: The effect in which a charged body changes the charge distribution of a nearby neutral body and induces in it a new charge distribution is called electrostatic indication. Substances can be electrified by the induction method.

Conservation of charge means that charge can neither be created nor destroyed. In an isolated system, the total charge remains constant

Electroscope: It is an instrument which is used for detection and testing the kind of small charges. It consists of a metal rod having a knob at one end and a pair of light thin metal leaves at the other end. The leaves and good part of the rod are enclosed in a jar.

Coulomb's law: Like charges repel and unlike charge attract each other. The force of attraction or repulsion between two point charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between them. Unit of charge is coulomb in SI System. In magnitude it is equal to the charge on 6.2×10^{18} electrons.

Electric Field intensity and Lines of Force: The region of space around a charge body, in which a test charge can feel the electric force of the charge is called electric field. The intensity of the field at a point in the field is the electric force experienced by a unit test charge placed at that point.

Electric potential: The work done or energy spent in moving a unit positive charge against an electric field is called electric potential. Its unit is volt.

The potential difference between two points is said to be one volt if on joule of energy is required to move one coulomb of charge from one point to the other.

Capacitor: The device used for storing charge and electrical energy is called capacitor. In principle, it consists of a pair of metallic plates separated from each other by a dielectric medium. The capability of storing charge is the capacitance of the capacitor. For charges Q on the plates having PD has capacitance $C = \frac{Q}{V}$.

The unit of capacitance is farad. It is numerically equal to the charge on either plate that will produce a PD of one volt across the plates of a capacitor. Capacitors in common use are of various kinds, size and shapes some capacitors are of fixed capacitance such as paper capacitor or mica capacitor. Radio tuning capacitors are variable type capacitors.

OBJECTIVE QUESTIONS

1. Fill in the blanks.

i. Electrical force is _______ gravitational force.

ii. Like charges _______ and unlike charges _______ each other

iii. In every atom there is a positively charged _______ and _______ revolve around it

iv. The diameter of an atom is about _______ the diameter of a nucleus

v. Valence electrons can be easily removed from the atoms of _______.

vi. A conducting material has enormous number of _______.

vii. Electrons always move from _______ potential to _______ potential.

viii. Electrons always accelerate in direction _______ the electric field.

ix. Coulomb, volt, joule, Newton, joule/coulomb are respectively the units of the following physical quantities

(i) (ii) (ii) (iv) (v)

x. Electrical force on a unit positive charge in the field is called _______.

SHORT ANSWER QUESTIONS

i. What is meant by earthing an object electrically

ii. State the law of conservation of charge

iii. How bodies are charged by rubbing then together.

iv. Define the term volt.

v. Define electric field and its intensity

vi. What is meant by electrostatic induction

vii. State Coulomb's law. Define coulomb

viii. Make a table o f the mass and charge of proton, neutron and electron.

COMPREHENSIVE QUESTIONS

1. Write a note on the atomic and electric nature of matter.

2. Distinguish between electrical conductor and insulators. Explain the electrical conductivity of materials on the basis of the atomic electrical theory of matter

3. A material is neither a perfect conductor nor a perfect insulator. Explain this statement.
4. What do you mean by electrostatic induction? How does a charged body attract small light pieces towards itself?
5. Write a comprehensive note electroscope
6. State Coulomb's law. Explain and define the unit of charge
7. What do you mean by electric field? How is it represented by lines of force? Provide figures for illustrations.
8. Define electric field intensity. Explain its magnitude and direction. Provide figures for illustrations.
9. Define and explain electric potential and its unit.
10. What is electric capacitor? Define and explain capacitance. Define the unit of capacitance.
11. What are the two basic ways of connecting capacitors? Obtain expressions for the equivalent capacitance of two capacitors when connected in (a) series and (b) parallel
12. What is a capacitor? What is the purpose of a capacitor? What factors determine the capacitance of a capacitor

    Discuss the construction of different types of capacitor. Illustrate with diagrams

NUMERICAL PROBLEMS

1. A charge of 25×10^{-9} C is placed in air at a distance of 6 cm from another charge -72×10^{-9}C. Find the electric force between them **[4.5×10^{-3} N]**
2. Two identical charges are 24 cm apart. They repel each other with a force of 1×10^{-3} N. Find each charge **[1.6×10^{-7} C]**
3. Two charges, 1.67 μC and -0.60μC are place 0.4 m apart. Find a point P between the charges where a test charge will not experience any force. **[0.6m from 2nd charge]**

4. A charge of (-0.05 μC) is placed in a horizontal field at the right side of the origin. The intensity of the field is 9.0×10^{4} NC^{-1}. Find the magnitude and direction of the force on the charge

[4.5×10^{-3} N, left ward horizontal]

5. Two identical charges q and q are r metres apart. Find the point where the intensity of the electric field will be zero.

[r/2 from each charge]

6. Find the acceleration of an electron in a field of intensity 1250 N/C^{-1}. Compare it with gravitational acceleration g.

[2.19×10^{13}ms^{-2}, 9.8 ms^{-2}]

7. In a hydrogen atom, electron revolves around the proton in a circular orbit of radius 0.53×10^{-10}m. Find the centripetal forces and the speed of the electron. **[2.20×10^{6} m.s^{-1}]**

8. A capacitor is charged to 420 μC. the potential difference across the plates becomes 140volt. Find the capacitance of the capacitor. **[3μf]**

9. The work done in bringing a charge of 8×10^{-7} C from infinity to a charged body is 2.0×10^{-4} J. Find the potential of the body. **[250 V]**

10. Two capacitors of 5 μ F and 10 μF capacitances are connected in parallel. Find the equivalent capacitance. A potential of 20 volts is connected across the combination.

(a) Find the voltage across the two capacitors

(b) The charge on each capacitor **[15μF, 100μC, 200μC]**

11. Capacitors of 3μF and 6μFcapacitances are connected in series. Find the equivalent capacitance.

Find the charge on each capacitor if 100V is applied to the combination **[2μF, 200μC]**

Chapter 16

CURRENT ELECTRICITY

In this chapter you will study

- Electric current and its unit
- Conventional current
- Electrical resistance and its unit
- Electric circuit; series and parallel combinations of resistors.
- Direct and alternating currents
- Heating effects of current: Joule's law
- Electric energy and electric power
- Short circuit and overloading
- Fuse, switch and circuit breakers
- Measuring electrical instruments: Galvanometer; ammeter and voltmeter

16.1 Flow of Charge: Current

Static charges and their effects were discussed in the last chapter. For practical point of view, the study of moving charges is more important. Moving charges give rise to electrical current, heat, light and magnetism.

When a charge is in motion, we say that current is flowing. In other words, the flow of charge is called current. The magnitude of the current is directly proportional to the magnitude of the charge and the velocity of charge.

Enormous number of free electrons is present in a conducting wire. In the absence of and external field, the resultant velocity of the randomly moving free electrons is zero. At any place of the wire, the current is zero. The free electrons in the wire can be given a net resultant velocity along the wire by means of a battery, which sets an electric field along the wire. In this way an electric current can be made to flow in a conducting wire, Fig. (16.1)

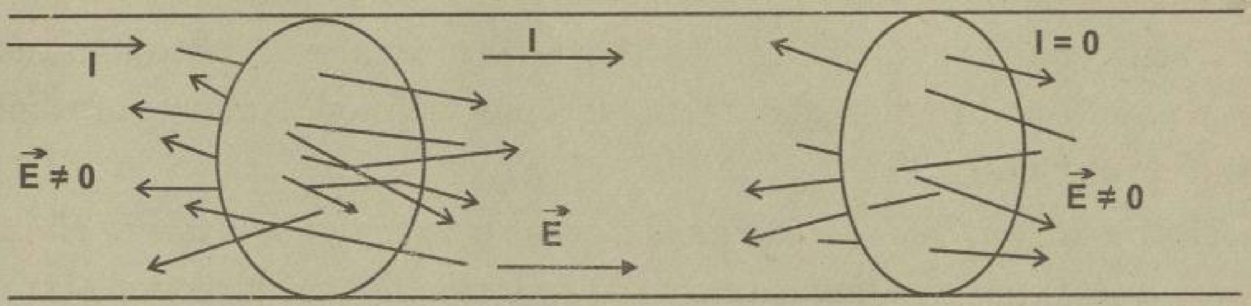


Fig.(16.1). (a) (b)

The number of electrons moving left is same as the number moving right

The number of electrons moving left is less than the number moving right

Similarly, there are positive and negative ions in an electrolyte. There can be imparted a net velocity along or opposite to an externally applied electric field. Their directed flow produces current.

If one end of a copper wire is connected to the positive terminal of an electric cell and the other end is connected to the negative terminal, there is difference of potential between the ends. In fact there is a PD across any two point of the wire. An electric field E is set up all along the wire. The free electrons will experience a force opposite to the direction of E. Now, the number of electrons crossing any cross section of the wire in the direction opposite to the field is more than that moving in the direction of the field, Fig. (16.1). In this way the flow of

electrons starts in the wire from its negative end to its positive end. Current begins to flow in the wire.

In order to maintain current continuously in the wire, it is necessary that the number of electrons that leave the negative electrode and reach the positive electrode must be supplied to the negative electrode. Otherwise, the arrival of opposite charge on each electrode will neutralize the charge on each electrode. The potential difference will vanish and current will stop. This task is done by an electric cell or an electric generator. A generator pumps positive charges, in its coil, to its positive electrode and negative charges to its negative electrode. In the externally connected wire, free electrons move from the negative to the positive electrode.

So far current was introduced as the flow of charge. The magnitude of current and the direction of current were not defined. Now we present the definition of current.

The time rate of flow of charge Q across any cross section of the path of flow is defined as electric current I. Generally, the direction of current is considered to be aligned with the positive current flow and opposite to negative current flow. If Q passes through a cross section in t second then the current I will be;

$$I = \frac{Q}{t} \qquad (16.1)$$

The SI unit of current is ampere and is denoted by A. *One ampere is the current when one coulomb of charge flows across a cross section of a conductor in one second.* The commonly used submultiples of the ampere are:

1 milliampere $= 1\,\text{mA} = 1 \times 10^{-3}\,\text{A}$

1 microampere $= 1\,\mu\text{A} = 1 \times 10^{-6}\,\text{A}$

The instrument used for measuring current is called ammeter.

16.2 Conventional Current

Before the discovery of electron is 1895, scientists thought that electric current is due to the flow of positive charge from the positive to the negative electrode of an electric cell. To day, we know that current is due to the flow of positive as well as negative charges. In metallic conductors, the current is due to the flow of electrons whereas in electrolytes and fluorescent tubes the current is due to the flow of positive and negative ions. Fig.(16.2) shows a simple current carrying circuit.

Inside the cell, the positive ions of the electrolyte move toward the positive electrode and the negative ions move toward the negative electrode. In the conducting wire, external to the battery, the current is due to the flow of free electrons. We see that in the same circuit, charges of opposite sign move in opposite direction.

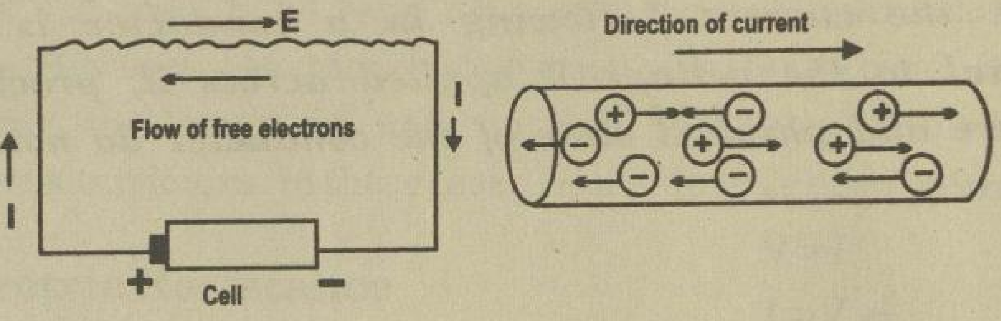


Fig. (16.2). Electronic current and conventional current

What is the direction of current? Is it in the direction of positive charges or negative charges?

A convention for labeling the direction is needed. The choice of representing the direction of current in a circuit by the direction of the flow of positive charges or negative charges is arbitrary.

The choice is in favour of positive charges and the convention adopted for labeling the direction of current is that **all charge carriers are positive and the direction of the conventional current is the direction in which such positive charges would move under the influence of the electric field.** By this convention, the current due to positive charge is the same as the conventional current and it moves from higher potential to lower potential. If the current is due to electrons or negative ions then it is represented by an equivalent conventional current carried by the movement of equivalent positive charges moving in a direction opposite to the motion of positive charges.

The external effects of the conventional current such its chemical, heating and magnetic effects are the same as that due to the actual current. So wherever we use the term current, it refers to the conventional current that flows from higher potential to lower potential.

16.3 Ohm's Law

You know that if voltage V is applied across a conductor, a current I flow through it, Fig. (16.3). A German scientist named Ohm performed a large number of experiments and in 1826 discovered a very useful law. The law states that ***the current I flowing in a conductor is directly proportional to the voltage V applied across it, provided the temperature and physical state of the conductor do not change.*** *Mathematically,*

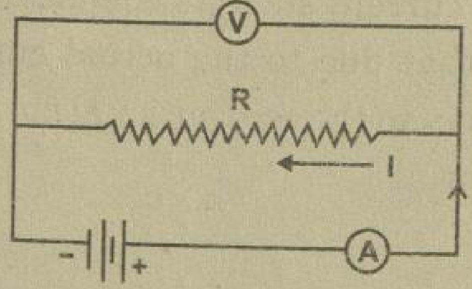
$$I \propto V$$

$$\Rightarrow V \propto I$$

$$\Rightarrow V = IR \qquad (16.2)$$

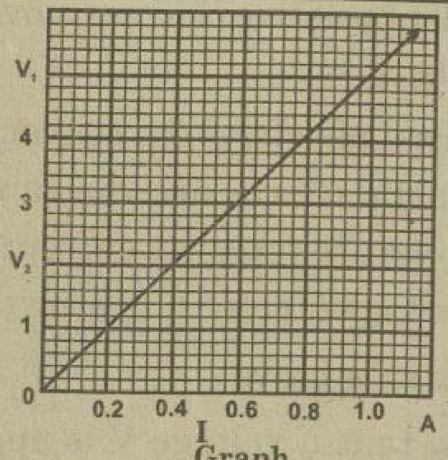
where R is the constant of proportionality and is known as the resistance of the conductor. The value of R depends upon the nature of the material of the conductor. R also depends upon the temperature, size and the physical state of the conductor. Further discussion on resistance is given in the next section.

You can easily verify Ohm's law by experiments. Take a thin and about one metre long metal wire. You can connect two or more electric cells in series to make batteries of different voltages. Connect on ends of the wire to the negative terminal and the other to the positive terminal of the battery. Measure the voltage across the wire by a voltmeter and the current in the wire, by an ammeter as shown in Fig. (16.3a). Draw the graph between I and V as shown is Fig. (16.3b). You will find out that the graph is a straight line. This kind of experiment can be performed on different wires. It is found that in each case $\frac{V}{I}$ is constant.



Circuit

Fig. (16.3a) Experimental verification of Ohm's law



Graph

Fig. (16.3b) Graph of V versus I

Ohm's law has been found valid for a wide range of currents in metallic conductors. However, note that the law is not valid for all conducting media. For example, the law is not valid in electronic tubes, transistors, ionic plasma, and electric arcs. In these cases I is not directly proportional to V

16.4 Electric Resistance

You must have observed that as the length of water pipe is increased, the flow of water through the pipe decreases. Moreover, water flows moor easily through a tube of wider diameter than a narrower diameter. In other words, a longer and narrower pipe offers more resistance to the flow of water than a shorter and wider pipe. Similarly, every conducting wire offers some resistance to the flow of electric current.

The property of a substance, which opposes the flow of current through it is called its resistance Quantitatively, *the electric resistance R of a conductor is the ratio of the potential difference between its ends to the current I produced in it:*

$$R = \frac{V}{I}$$

Resistance R depends on the nature, dimension and temperature of the conductor.

Unit of Resistance:

SI unit of resistance is ***ohm***. It is defined, as the resistance of a conductor through which a current of one ampere flows when a potential difference across it ends is one volt. It is denoted Ω (omega):

$$1\Omega = \frac{1\text{ volt}}{1\text{ampere}}$$

The commonly used multiples of ohm are:

$$1\text{ kilo-ohm} = 1\text{k}\,\Omega = 10^3$$

$$1\text{Mega-ohm} = 1\text{M}\,\Omega$$

A short zigzag line represents a resistor.

Measurement of Resistance

The resistance of resistor can be measured by a simple method illustrated in

Fig.(16.4). An ammeter measures the current through the resistor. The voltage across it is measured by the voltmeter connected across its ends. By applying Ohm's law, the ratio of V to I gives the resistance R of the resistor.

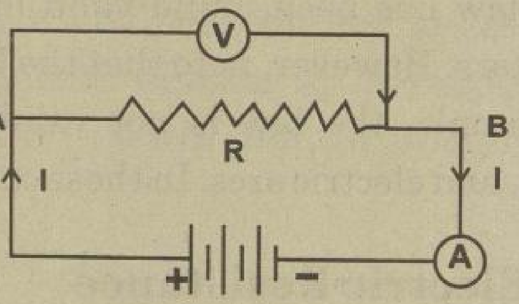


Fig. (16.4). Measurement of resistance by Ohm's law

Specific Resistance

The resistance of a conductor is due to the continual collisions of the free electrons in the conductor with the ionic lattice of the conductor. Resistance of a conducting wire depends on ***the length***, ***cross sectional area***, ***nature of the conductor***, and ***temperature*** of the wire. For a wire of given material and at constant temperature, the resistance R varies directly with its length L and inversely with it cross section-sectional area A.

Symbolically: $R \alpha \frac{L}{A}$

$$R = \rho \frac{L}{A} \qquad (16.3) \quad \text{(temperature = constant)}$$

where ρ is the constant of proportionality and is called the resistively or the specific resistance of the material of the wire. The value of ρ depends upon the nature of the material. The resistances of wires of same length and of same cross section but made of different materials such as copper; aluminum, iron and brass are different. This is because the nature of these materials is different. In Eq.(16.3), if $L = 1m$, $A = 1m^2$ then $R = \rho$. Thus ***the specific resistance ρ of a material is defined as the resistance of a conductor having unit cross-section and unit length. Its unit as seen from Eq. (16.3) is ohm-metre.***

The specific resistance of a few metals is given in Table. (16.1)

Table. 16.1

Metal	Specific resistance in $10^{-8}\,\Omega$m.
Silver	1.62
Copper	1.69
Aluminium	2.75
Tungsten	5.25
Platinum	10.6

The resistance of a conductor increases with rise in its temperature. This is discussed in the next sub section.

Example 16.1: The potential difference across the filament of an electric bulb is 220 V. The current passing through the filament is 440 mA.

(a) What is the resistance of the filament?

(b) If the PD is increased to 250 V, then how much current will flow through the filament.

Solution:

(a) Voltage $= V = 220V$

Current $= I = 440mA = 440\times10^{-3}A$

According to Ohm's law

$$R = \frac{V}{I} = \frac{220V}{440\times10^{-3}mA} = 500\,\Omega$$

(b) When the voltage is increased, the resistance, being a property of the filament, does not change.

Increased voltage $= V' = 250\,V$

The constant resistance of the filament $= R = 500\Omega$

Current through the filament $I' = \frac{V'}{R} = \frac{250V}{500\Omega} = 0.5A$

Example 16.2: Calculate the resistance of one metre long copper wire of 2mm diameter.

Length of the wire $= L = 1m$

Diameter of the wire $= d = 2mm = 2.0\times10^{-3}\,m$

Cross section of the wire $A = \frac{\pi d^2}{4} = \frac{3.14\times(2.0\times10^{-3}m)^2}{4} = 3.14\times10^{-6}m^2$

Specific resistance of the wire, as given in Table (16.1) is

$$\rho = 1.69 \times 10^{-6}\,\Omega\text{m}$$

According to the formula for resistance

$$R = \rho\,\frac{L}{A}$$

$$= \frac{1.69 \times 10^{-6}\,\Omega\,\text{m} \times 1\text{m}}{3.14 \times 10^{-6}\text{m}^2}$$

$$= 0.54 \times 10^{-2}\,\Omega$$

$$\Rightarrow \quad R = 5.4\,\text{m}\Omega$$

Effect of Temperature on Electrical Resistance

A metallic conductor is commonly in a crystalline solid state. Individual atoms release their valence electrons and the remaining ions occupy fixed position in the form of a regular lattice. The random motion of free electrons in the absence of an electric field was discussed in section 16.1 and the drift motion of the electrons in the presence of an electric field was also discussed in section (16.1). When temperature of a conductor is increased then the amplitude of the vibrational motion of positive ions in the lattice increases. This causes an increase in the rate of collisions of the free electrons with lattice ions. The result is that the resistance to the flow of current increases. The increase in electrical resistance depends on the nature of the material, the initial resistance and the rise in temperature. The temperature dependence of resistance can be expressed by the following mathematical equation

$$R_t = R_o(1 + \propto t) \qquad (16.4a)$$

$$R_t - R_o = \alpha\, R_o t \qquad (16.4b)$$

$$\Rightarrow \alpha = \frac{R_t - R_o}{R_o t} \qquad (16.4c)$$

R_t and R_o are respectively the resistance at temperature t and at a reference temperature, say 0°C. The ***constant a, called the temperature coefficient of resistance, is the increase in resistance per ohm per degree rise in temperature.*** The value of a is different for different materials. For most metals and alloys, resistance changes slightly and linearly with temperature over a wide range. This property of materials is used to construct electrical resistance thermometer, such as, platinum resistance thermometer.

Electrical Resistance Thermometer

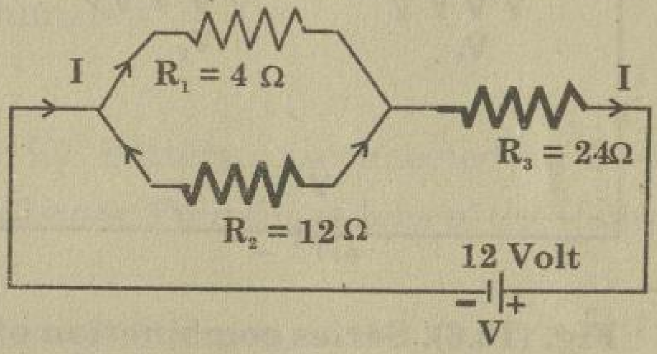


Fig. (16.10). Platinum resistance Thermometer

The conductor used in resistance thermometer is usually a platinum wire whose ends are welded with thick copper wire, Fig. (16.10). Before measuring the temperature of a substance, the thermometer is placed in melting ice and its resistance at 0°C is measured. Let it be R_o. Then the bulb of the thermometer is placed into the substance whose temperature is to be measured. The resistance of the platinum wire is again measured. Let this time its value R_t. According to Eq. (16.4c)

$$t = \frac{R_t - R_o}{R_o \alpha}$$

The value of a for platinum is $3.9 \times 10^{-3}/°C$.

The temperature range of resistance Thermometer is from -260 °C to 630 °C.

16.5 Combinations of Resistances.

In an electric circuit, various types of electrical instruments, appliances and components etc. are connected in various ways. In a circuit diagram, appliances are represented by their equivalent resistance. In reality, there are two basic ways of connecting resistors: series combination and parallel. Based upon these combinations, there is a useful combination: series and parallel combination. Each one of them is now discussed in detail.

Series Combination of Resistors

When two or more resistors are connected end-to-end, then they are said to be connected in series. In Fig.(16.6) three resistors R_1, R_2 and R_3 are connected in series.

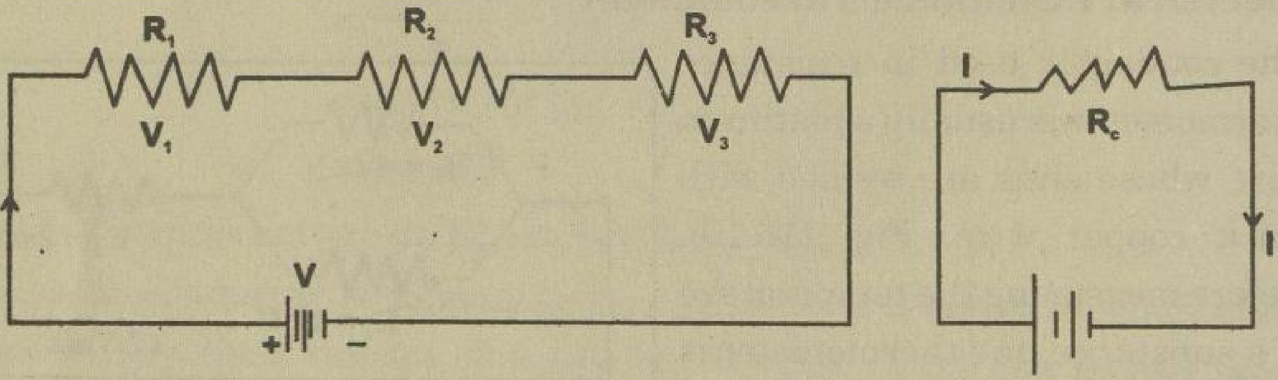


Fig. (16.6). Series combination of resistors

This combination has the following characteristics

i. The circuit provides a single path for the flow of current

ii. The current in all parts of the series circuit is the same.

iii. The sum of the voltages across individual is equal to the voltage of the battery applied to the circuit.

If the battery voltage is V, current in the circuit is I and the voltage drops across R_1, R_2, R_3 are respectively V_1, V_2, V_3, then

$$V = V_1 + V_2 + V_3$$

$$= IR_1 + IR_2 + IR_3$$

$$= I(R_1 + R_2 + R_3)$$

$$\frac{V}{I} = R_1 + R_2 + R_3$$

$$V = IR$$

By Ohm's law: $\frac{V}{I} = R$, which is called the equivalent resistance of the combination. Thus

$$R = R_1 + R_2 + R_3$$

iv. The equivalent resistance of the series combination is sum of the individual resistances.

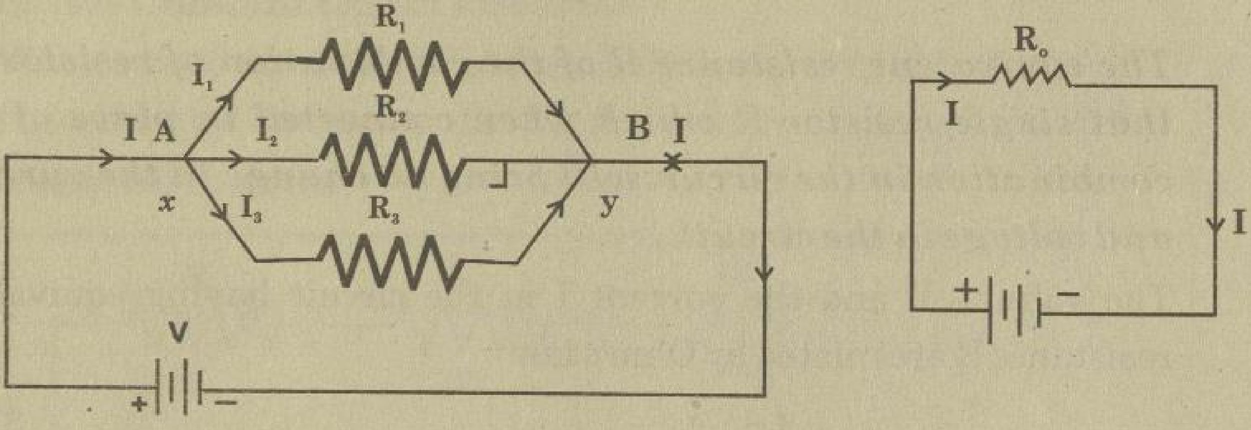


Fig.(16.8). Parallel combination of resistors

is connected at one point and the other end is connected to another point, then they are said to be connected in parallel as shown in Fig. (16.8). In this figure, three resistors R_1, R_2, R_3 are connected in parallel to a battery of voltage V

The parallel combination has the following characteristics.

i). The circuit provides alternative paths for the flow of current. The total current I in the circuit distributes itself at one junction and collect itself at the other junction. In Fig. (16.8), there are three paths for the current at the junction point A. Currents passing through the three paths collect together at the junction point B.

ii). Voltage across each resistor of a parallel combination is the same and is equal to the applied voltage V.

iii) The sum of the currents in the various resistors is equal to the total current in the circuit.

In Fig. (16.8), the total current I is:

$$I = I_1 + I_2 + I_3$$

$$= \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

Dividing both side by V

$$\frac{I}{V} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

(iv) $$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

where R= V/I is the equivalent resistance of the circuit. The equivalent resistance R is less than each of the resistance R_1, R_2 and R_3

Example 16.4: In Fig. (16.9), a 12V battery is connected to a parallel combination of 8Ω, 12Ω and 24Ω resistors. Find the values of the following quantities

(a) Equivalent resistance of the combination

(b) Current through each resistor

(c) Current through the circuit

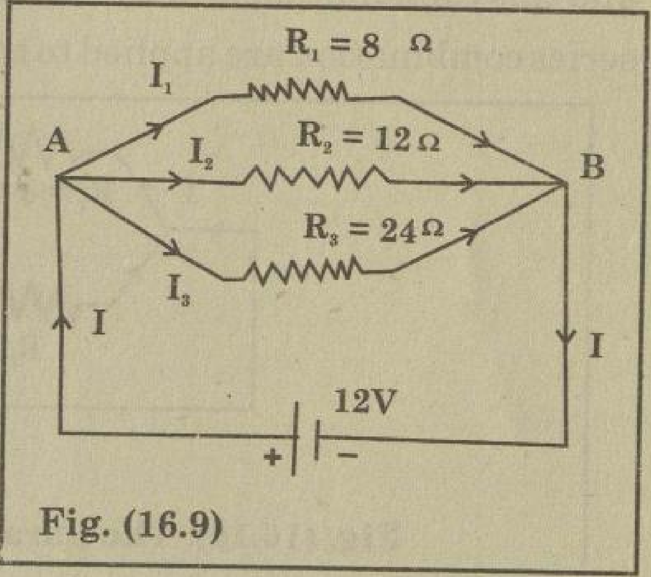


Fig. (16.9)

Solution:

The resistances connected in parallel are

$R_1 = 8\Omega, R_2 = 12\Omega, R_3 = 24\Omega$

(a) The equivalent resistance of the combination is given by

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$= \frac{1}{8\Omega} + \frac{1}{12\Omega} + \frac{1}{24\Omega}$$

$$\frac{1}{R} = \frac{3+2+1}{24\Omega} = \frac{1}{4\Omega}$$

Hence: $R = 4\Omega$

(b) Voltage across each resistor is 12volts. Currents passing through R_1, R_2, R_3 are respectively given by

$$I_1 = \frac{V}{R_1} = \frac{12V}{8\Omega} = 1.5A$$

$$I_2 = \frac{V}{R_2} = \frac{12V}{12\Omega} = 1A$$

$$I_3 = \frac{V}{R_3} = \frac{12V}{24\Omega} = 0.5A$$

(c)The total current in the circuit is

$$I = \frac{V}{R} = \frac{12V}{4\Omega} = 3A$$

which is equal to the sum of I_1, I_2 and I_3

Series-cum-Parallel Combination of Resistors

Sometimes in the same circuit, one has to use some resistors in series and others in series in parallel. In Fig.(16.10), resistors R_1 and R_2 are in parallel and this combination is in series with R_3. In this case the rules of parallel and series combination are applied to the complete circuit.

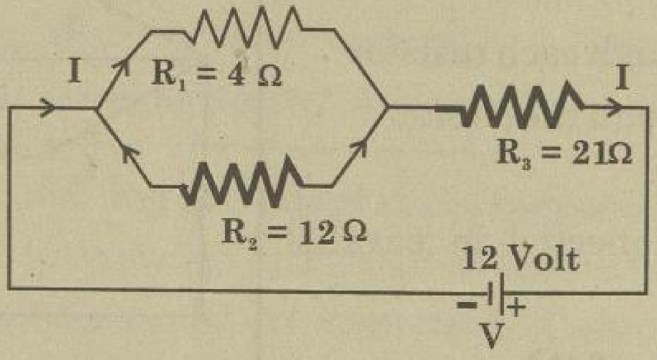


Fig. (16.10). The parallel and series combinations

Example (16.7): Find the values of the following quantities for the circuit shown in Fig (16.10)

(a) The equivalent resistance of the circuit.

(b) Current in the circuit.

(c) Voltage across each resistor.

(d) Current in each resistor.

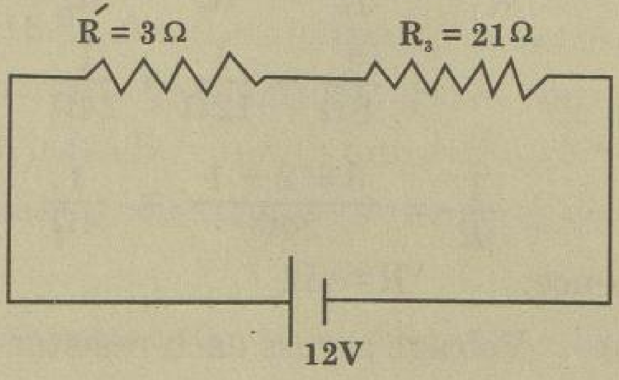


Fig. (16.11). Equivalent resistance of the given circuit

Solution:

(a) The equivalent resistance of the parallel combination of R_1 and R_2 is:

$$\frac{1}{R'} = \frac{1}{4\Omega} + \frac{1}{12\Omega} = \frac{3+1}{12\Omega} = \frac{1}{3\Omega}$$

Hence

$$R' = 3\Omega$$

The equivalent resistance of R' and R_3 is

$$R = R_3 + R' = 3\Omega + 21\Omega = 24\Omega$$

(b) Current in the circuit is

$$I = \frac{V}{R} = \frac{12V}{24\Omega} = 0.5A$$

(c) The voltage across R_1, R_2, R' is same and is equal to

$$V' = IR' = 0.5A \times 3\Omega = 1.5V$$

The voltage across R_3 is

$$V_3 = IR_3 = 0.5A \times 21\Omega = 10.5V$$

(d). The currents in R_1, R_2 and R_3 are

$$I_1 = \frac{V'}{R_1} = \frac{1.5V}{4\Omega} = 0.375A$$

$$I_2 = \frac{V'}{R_2} = \frac{1.5V}{12\Omega} = 0.125A$$

$$I_3 = I = \frac{V}{R} = \frac{12V}{24\Omega} = 0.5A$$

16.6 Electric Energy

Energy is that property of a system that can be used to do work. Electric energy is commonly obtained from mechanical, chemical energy or heat energy. According to our need we use electrical energy to turn fans, light bulbs and operate television set etc. An electrical device cannot work until a potential difference (PD) is applied across it and current flows through it. Thus the availability of electrical energy is related to the voltage and current I in the circuit. We want to find out this relation between V, electric energy and current I.

Suppose the PD between two points A and B of a wire in a circuit is

$$V = V_A - V_B$$

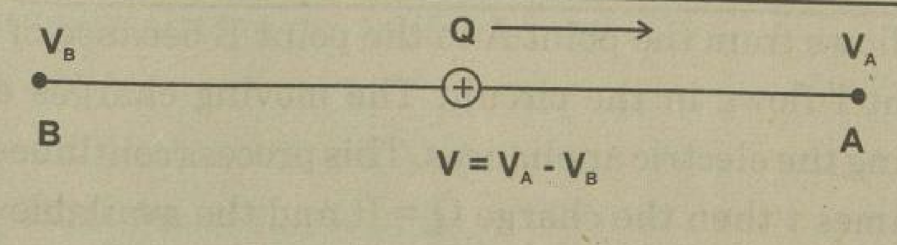


Fig. (16.12)

where V_A is greater than V_B, Fig. (16.12). According to the definition of PD, the work required to carry one coulomb of charge from B to A is V. To carry Q coulomb of charge from B to A, the work required is

$$W = QV \tag{16.5}$$

The electric potential energy of the charge Q at the point A is greater than its electrical PE at the point B by the amount QV. This energy can be obtained back from the charge Q. For example, if the charge Q is released free from the point A, it will move toward B with certain acceleration. If there is no resistance in its path of motion, it will reach B with kinetic energy equal to QV. It is this energy of moving charges that we call it 'Electrical Energy'. If the motor of a fan or the filament of a bulb etc is placed in the path of flowing charges then the KE of the charges, turn the motor or lights the bulb.

Let us extend this concept and apply it to the continuous flow of current in a circuit. In Fig. (16.13), different types of appliances are connected to a V-volt battery. The appliances are represented collectively by a closed box. Point A and B are terminals of the battery. The charge Q at point B is pushed or pumped to the point A through the solution of the battery by the chemical action in the battery. The battery raises the PE of the charge by the amount QV.

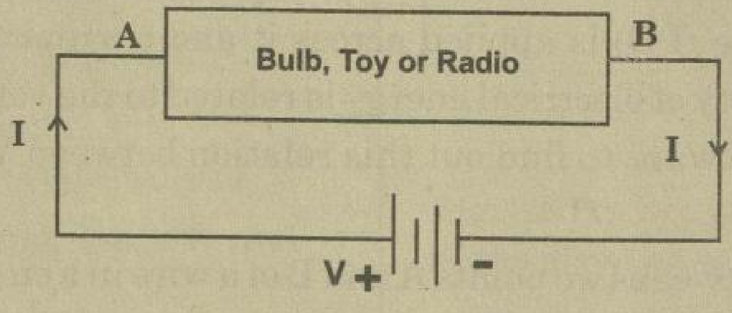


Fig. (16.13)

The charge Q, flows from the point A to the point B because of PD between them. A current I flows in the circuit. The moving charges expend their energy in running the electric appliances. This process continues. If current I is flowing for times t then the charge Q = It and the available or expended energy is

$$W = QV = IVt. \qquad (16.5a)$$

Note that besides time, the available electrical energy or the expended electrical energy depends on the voltage and the current. Using electric appliances we consume electrical energy. Electrical energy, which we call electricity, is supplied to our houses. We expend electricity and pay bills for its consumption.

The electric appliances in a circuit have necessarily some resistance R to the flow of current through them. This resistance opposes the flow of charge (electrons) and converts the KE of the moving charges to heat. A current carrying wire gets warm. According to Ohm's law:

$$V = IR \quad \text{or} \quad I = \frac{V}{R} \qquad (16.6)$$

Eliminating V from Eqs (16.5a) and (16.6), we see that the heat produced in resistance R is

$$H = I^2Rt$$

In electric appliances such as heater, electric iron, bulb etc, the resistance R is designed to be large. However, in the design of an appliance such as electric fan, we need conversion of electrical energy to mechanical work and want to reduce R to the minimum. A running fan does get warm and consume some energy as heat. Similarly, some energy is always wasted in form of heat in running an electric device.

Example 16.8. An electric fan is connected to 220V supply line and runs for 10 hours. It draws a current of 1A from the voltage line. The resistance of the motor of the fan is 0.2 R. Find the following:

(a) How much energy is supplied by the line?

(b) How much energy is converted into heat?

Solution:

(a) The energy supplied to run the fan is

$$W = IVt$$

$$= 1\,A \times 220V \times (10 \times 60 \times 60\,\text{sec})$$

$$\Rightarrow W = 7920000\,J = 7.92 \times 10^6\,J.$$

(b) Heat produced in the motor is

$$H = I^2Rt$$

$$= (1A)^2(0.2\,\Omega) \times 10 \times 3600\text{sec}$$

$$= 7200\,J$$

Note the total supplied energy is quite large compare with the heat energy. The energy is mainly consumed in running the electric motor of the fan.

16.7. Electric Power

Power is defined as the time rate of doing work or the time rate of expending energy. It is thus obtained by dividing the energy W by the time t, which is taken to do the work or to expend the energy. Symbolically

$$P = \frac{W}{t} \qquad (16.7)$$

When W is electrical energy then P is electric power. Battery or electric generator is the source of electric power. The machine, run by electricity, expends electric power. When current I is supplied by a generator of voltage V to an appliance, then the required energy is

$$W = IVt \qquad (16.8)$$

Dividing by t, the required power is

$$P = IV \qquad (16.9)$$

$$\text{Electric power} = \text{Current} \times \text{Voltage} \qquad (16.10)$$

This formula is often called Watt's law.

If the electric power is consumed in producing heat in a resistor R, then according to Ohm's law

$$V = IR \quad \text{or} \quad I = \frac{V}{R}$$

Eliminating V or I from Eq. (16. 9), we get

$$P = I^2R = \frac{V^2}{R} \qquad (16.11)$$

Unit of Power: The unit of power is called watt, which is equal to joule per second. The electric bulbs used in houses are commonly of 25W, 40W, 60W and 100W. Electric iron and electric heaters are of 1000W. Other units of power are

$$1\text{kW} = 1000\text{W}$$

$$1 \text{ horse power} = 1\text{hp} = 746\text{W}$$

Example 16.9. The resistance of an electric heater is 500Ω. A current of 2A is passing through the element of the heater. Find its power of expending electrical energy.

Solution:

The power of the heater for consuming electrical energy is

$$P = I^2 R = 2\text{A} \times 2\text{A} \times 500\Omega$$

$$P = 2000\text{ W} = 2\text{kW}$$

Example 16.10. An electric bulb is labeled as 220V and 100W. Find the resistance of the filament of this bulb.

Solution: Power of the bulb for consuming electrical energy is

$$P = \frac{V^2}{R} \Rightarrow R = \frac{V^2}{R}$$

Putting the given values in this equation

$$R = \frac{220\text{V} \times 220\text{V}}{100\text{W}} = 484\Omega$$

kilowatt-hour

Commercially, electrical energy is consumed on a large scale. Joule is a small unit for measurement of large energy. There is a need for a larger unit of energy. A larger unit of energy is kilowatt-hour (kWh). One kilowatt-hour is the amount of energy, which is obtained from one-kilowatt power in one hour:

$$1\text{ kWh} = 10^3\text{ W} \times 3600\text{ s}$$

$$= 3.6 \times 10^6\text{ W s}$$

$$1\text{ kWh} = 3.6 \times 10^6\text{ J}$$

The electric meter fixed in houses measure energy in kWh. The bill is prepared on the basis of kWh units. It is commonly called unit of electricity. If the rate per unit is known, the electricity bill can be calculated.

Total cost of electricity = Number of units × cost per unit

= Number of kWh × cost of unit

Example 16.11 In a shop, 4 bulbs of 60W, 2 bulbs of 100W and 2fans of 75W are on for 10hours daily

(a) How much electrical energy is consumed in 30 days

(b) If the rate per unit is 75 paisa per unit, what will be the monthly bill

Solutions:

(a) Daily consumption of electricity in 4 bulbs of 60W each is

$$W_1 = 4 \times 60W \times 10hr = 2400W\text{-}hr$$

Daily consumption in 2 bulb of 100W each is

$$W_2 = 2 \times 100W \times 10hr = 2000W\text{-}hr$$

Daily consumption in 2 fans of 75 W each

$$W_3 = 2 \times 75W \times 10hr = 1500W\text{-}hr$$

Daily consumption of electricity

$$W_d = (2400 + 2000 + 1500)\ W\text{-}hr = 5900W\text{-}hr$$

Monthly (30days) consumed energy = 5900W - hr ×30 = 177000W-hr=177kW - hr

$W_d = 177\ kWh = 177unit$

Cost per unit = Rs. 0.75/unit

Electricity bill = 177 units × Rs.0.75/unit

= Rs: 132.75

16.8. Direct Current and Alternating Current

You know that when the terminals of a cell or a battery are connected by a conducting wire then current starts flowing from the positive terminal to the negative terminal of the battery. The characteristic of this type of current is that it always flows in one direction. Such a current, which does not change its direction or maintains its unidirectional flow in a wire, is known as direct current or DC. On the contrary, there is a kind of current, which changes its direction in a circuit element quite a number of times in one second. Such type of current is known as alternating current or AC. The current supplied to houses, factories, offices etc are AC. This type of current will now be explained with the help of Fig. (16.14).

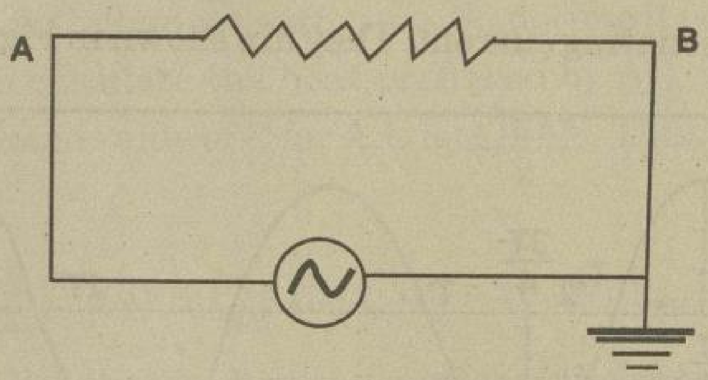


Fig. (16.14). Illustration of alternating current (A.C)

Instead of a battery, suppose the ends A and B of a resistor are connected to such a generator that end B is always connected to earth and is at zero potential. The end A is at potential V and varies with time in a way, which is illustrated by V-t graph in Fig. (16.15). From a starting time $t = 0$ to a time $t = T$, the graph has a characteristic shape. After time T, the graph repeats itself. The time duration T is called the time period. Now let us see what kind of current will pass through the resistor AB due to the varying potential V at A.

The graph (16.15a) shows that at what time t voltage V is positive (V^+ and at what time V is negative (V^-). It also shows how much is V^+ and V^-. For V^+ the current is I^+ and flows from A to B, that is $A \xrightarrow{I^+} B$. For V^-, the current is I^- and flows opposite to the earlier direction, that is, it flows from B to A: $B \xrightarrow{I^-} A$. It is also obvious from the graph in Fig. (16.15b) that from $t = 0$ to $t = \frac{T}{2}$ the potential is V^+ and the current is I^+. From $\frac{T}{2}$ to T potential is V^-. Potential of A is less than B and current is I^-. Note that I^+ and I^- are each unidirectional but their magnitudes vary with time. In fact each varies from zero to a maximum value in a specific manner.

After time T, the second period of voltage and of current starts. V repeats itself. The current in the resistor AB changes its direction and magnitude in exactly the same manner as they do in the earlier period of time. This alternation in voltage and current repeats itself after every time period T. The voltage across AB is known as alternating voltage. The current through AB is known as alternating current. They are shown in Fig. (16.15)

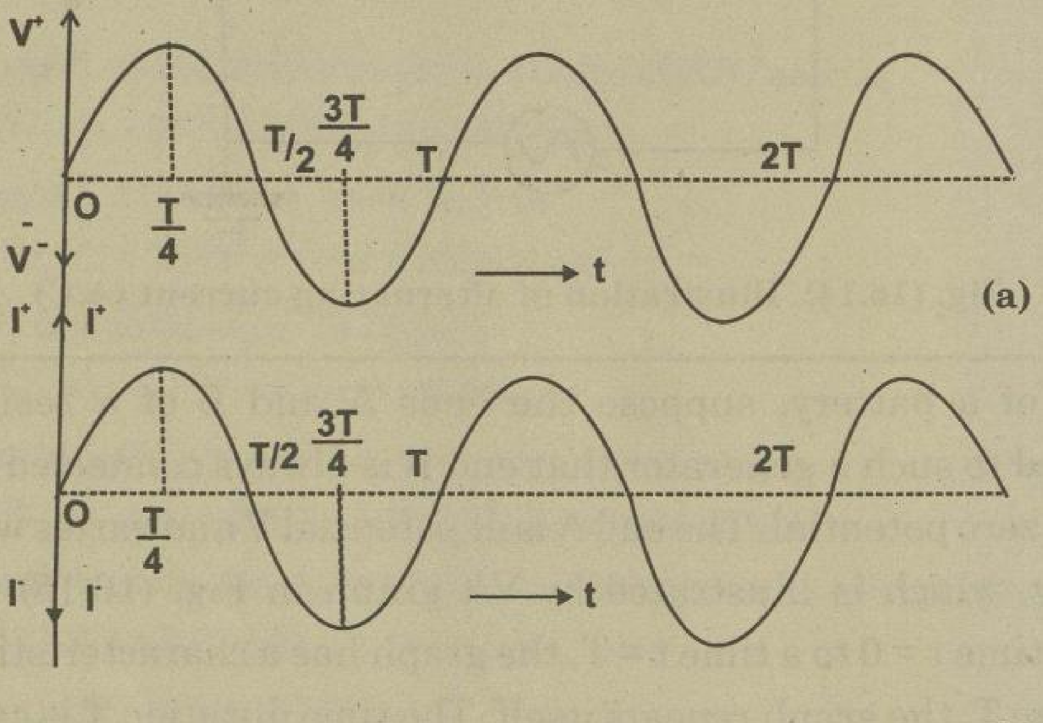


Fig. (16.15) (b)

The changes through which the voltage and current go in one period T is called one cycle. The number of cycles the A.C. completes in one second is called the frequency of A.C. The voltage and current supplied to our houses are alternating and each is of frequency 50 cycles s^{-1}. The maximum value of the voltage is 250V. The current draw by an appliance from the 250V supply line depends on the nature of the appliance. An electric iron is a high power appliance and draws high current and expends a lot of electrical energy. A radio is a lower power device, draws very little current from the supply line and consumes very little electrical energy.

You know that when current I passes through a resistor R for a time t, the heat produced is given by

$$H = I^2Rt = IVt = \frac{V^2}{R}t$$

Note that I^2 is always positive whether I is negative or positive. This means that the heating effect of current does not depend on the direction of the current. The heating effect of A.C is the same as that of D.C. However, the value of current in A.C. changes with time. Sometime it is zero and sometime it is maximum. To calculate the heat produced by AC, we use the average value of I^2. the average value of I^2 for A.C is $\frac{I^2 max}{2}$. Thus the amount of heat produce by A.C is

$$H = \frac{1}{2} I^2_{max} Rt = (\frac{1}{\sqrt{2}} I_{max})^2 Rt = (0.707 I_{max})^2 Rt.$$

This equation implies that for heating purposes the average value of A.C. is $0.707\ I_{max}$. In other words, $0.707\ I_{max}$ is that equivalent D.C whose effect is the same as that of A.C. having maximum value I_{max}.

16.9. Dangers of Electricity and Safety Measures

Large quantity of electricity is generated at electric power stations. It is then distributed from town to town through overhead high voltage lines. Electricity is consumed in factories, offices, hospitals and schools etc. Electricity is a very clean and convenient source of energy. However, electricity could by very dangerous if proper care and safety measures are not taken. You are warned about a few of the main dangers of electricity.

Overhead Cable

Overhead cables are at thousands of kilovolts above the ground voltage. They can cause high currents through conductors. The high currents are dangerous and can cause death by touching the cables. Accidents have happened when kite lines have touched cables. So, avoid climbing the installation poles. Avoid flying kites near the cables, especially with the metal kite lines.

Lightning Strikes:

Charged clouds can strike the ground. Then huge current flows between the earth and the ground. Houses and other buildings must be protected from lightning strikes. For this purpose pointed lightning conductors are projected well above the building and are earthed at the lower end.

It is risky to be out in an open ground or be near an isolated tree or building in lightning clouds.

Fire Hazards:

Broken pieces of wires, loose, dirty plug pins and too many appliances connected to one socket may overheat the wiring in a building. It may be enough to melt the insulation and cause a fire.

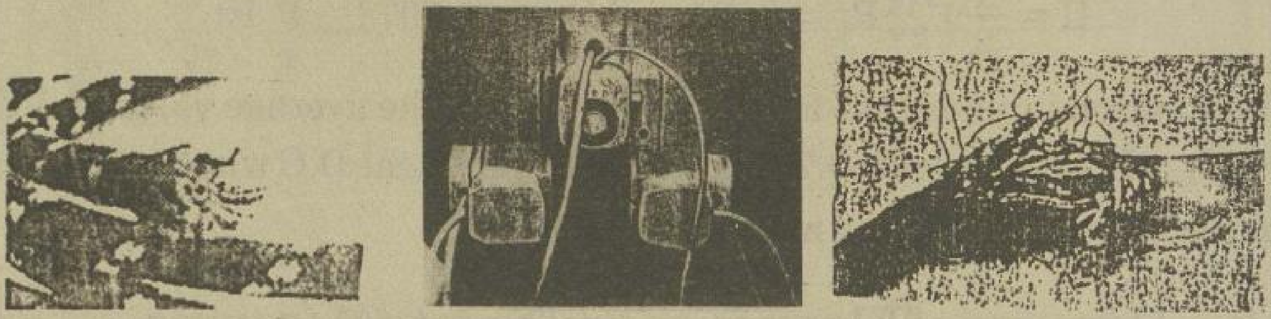


Fig.(16.16)

TV Danger:

TV set is probably the most dangerous thing in the house. The voltages inside a working TV set can reach up to 25000 V. Some parts are still live even when the set is switched off. So for safety sake, never remove the back off. Always switch off the set from the supply plug.

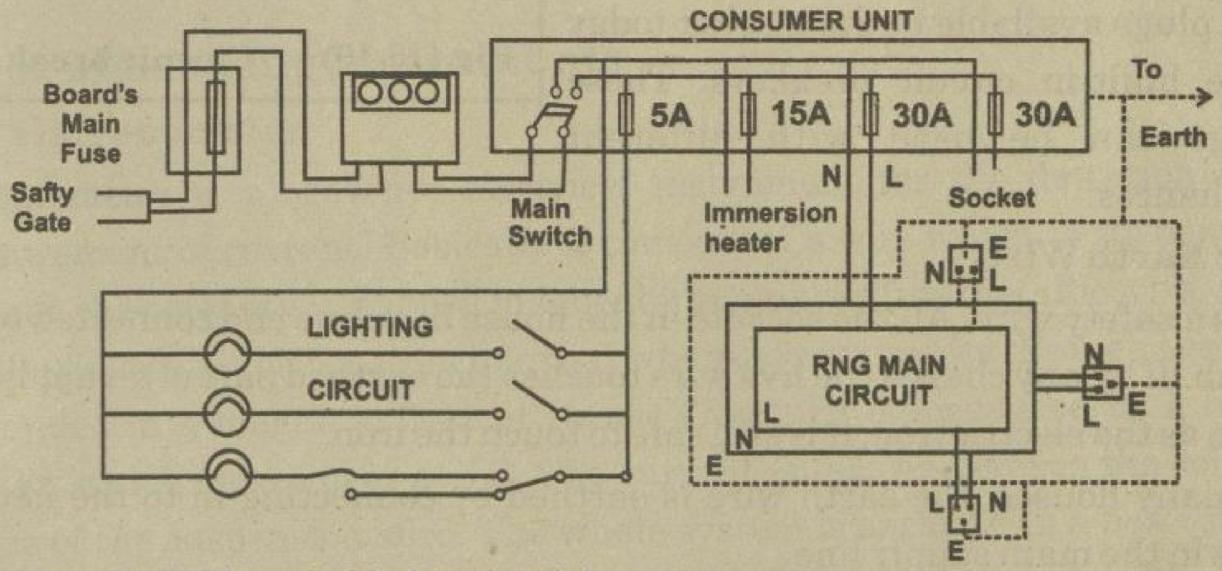
Car Battery Danger:

A 12-V car battery is not dangerous but if a conducting wire or spanner is connected to the wires of the battery, it can cause enough current to start a fire. A wise mechanic disconnects the battery before starting the work.

Safe Use of Household Electricity:

You have learnt that a battery provides current, which always flows in one direction. It is called DC (direct current). The electricity supplied to our houses is AC (alternating current). AC means that the current in the supply line changes it direction many times in one second. In fact, the electricity supplied to our houses changes direction 50 times in one second. Its frequency is 50 cycles and its voltage is 240 V. For the safe use of electricity you are expected to know the following about the house hold electricity.

The main supply cable into each house contains a ***live wire*** and a ***neutral wire***. All appliances in the house are connected in parallel to the main line. The cable for each appliance in the house contains an earth wire as well as a live and neutral lines. (Fig:16.17)


CONSUMER UNIT
Board's Main Fuse
Safty Gate
Main Switch
5A
15A
30A
30A
To Earth
N
L
Immersion heater
Socket
E
N
L
LIGHTING
CIRCUIT
RNG MAIN CIRCUIT
N
L
E
N
L
E
L
N
E

Fig,(16.17) Household electric wiring

The Main Switch:

It is fitted in the live wire. Through this switch, you turn off and on the electricity to the entire house.

The Main Fuse:

A fuse is a short piece of thin wire of low melting point. Like the main switch, it is connected in the live wire. The fuse overheats and melts if too much current flows through it. If a fault develops, the fuse melts and breaks the circuit before any thing else is heated to catch fire. Fig,(16.18) shows typical fuse devices. In fact, a fuse is placed in each circuit in the home wiring.

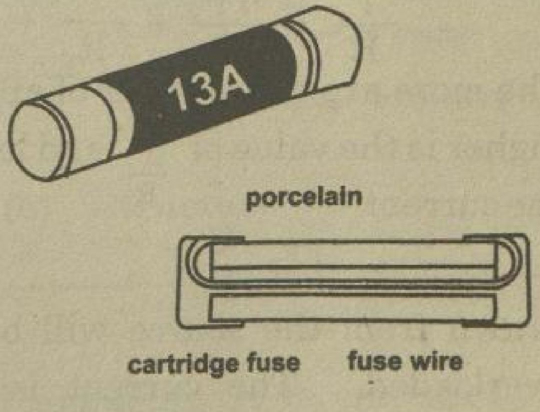

13A
porcelain
cartridge fuse
fuse wire

Fig.(16.18) Samples of fuses

Circuit Breaker:

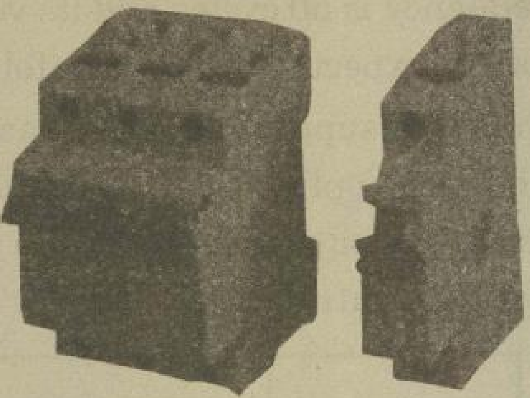


Fig.(16.19) Circuit breakers

Circuit barkers are now replacing fuse boxes. They are automatic switches, which break the current when the current rises above the specified value. It can be turned on again by pressing the button.

The plugs available in the market today have built-in circuit breakers. These plugs can be used with different appliances.

The Earth Wire:

It is a safety wire. All the sockets in the house have one end connected to the earth. If by any chance the live wire touches the earthed part of an appliance such as the electric iron, it is still safe to touch the iron.

In many houses, the earth wire is earthed by connecting in to the neutral wire in the main supply line.

Overloading

Let the household appliances be replaced by their equivalent resistances R1, R2, R3, R4, . . . The resistance R offered by the appliances to the supply voltage V is given by:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \cdots$$

The more are the number of appliances connected to the supply voltage the higher is the value of $\frac{1}{R}$ and less is the value of R. According to Ohm's law the current

$$I = \frac{V}{R}$$

drawn from the source will be very high. We say the voltage source is overloaded. The current is distributed over the various appliances. However, each one of them draws a share of very small current, but the sum of the currents is the large current

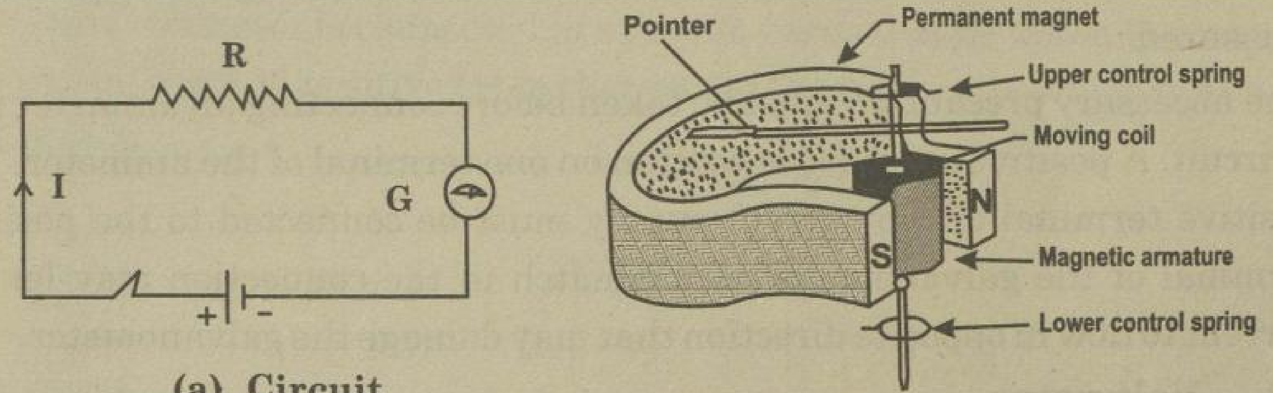
Short Circuit:

It is possible that due to negligence, fault in the wiring or any other reason that the live wire comes in contact with the neutral wire or the earth wire. The live wire is then said to be short-circuited. Very large current will start flowing through the short circuit. The wires will heat up and can catch wire. In such circumstances, the fuse or circuit comes into operation and breaks the circuit.

16.10. Measuring Instruments

(A). Galvanometer

Galvanometer is a sensitive electrical instrument for the detection and measurement of current. Basically it consists of a coil, which is suspended between the poles of a u- shaped magnet by means of a fine metallic wire. Fig. (16.20a) it is based on the principle that when current passes through the coil suspended in a magnetic field, it turns. This turn is measured by a light pointer, which moves over a dial. The current enters and leaves the coil by means of the suspension wire. The whole system is enclosed in a box with a glass window for the pointer and the dial. Fig (16.20 b)



(a) Circuit

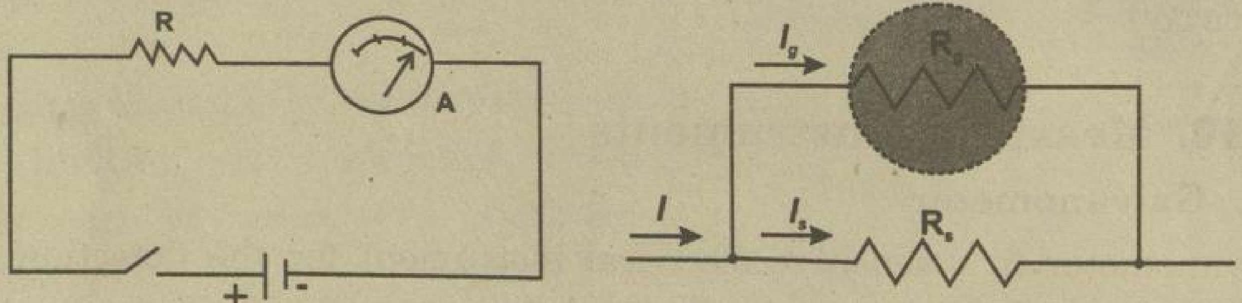
(b) Structure

Fig. (16.20) Galvanometer

(B) Ammeter

A current-measuring instrument is called ammeter. It is essentially a galvanometer, which is modified for measuring large current. The modification is accomplished by connecting a suitable low resistance R_s in parallel with terminals of the galvanometer, Fig. (16.21). R_s is called the ***shunt resistance***.

Ammeter is connected in series with a circuit. The reason is that the current in the circuit to be measured must pass totally through the ammeter. This is only possible if the ammeter is connected in series with the rest of the circuit.



(b) Use of ammeter in a circuit

(a) Conversion of galvanometer to ammeter

Fig. (16.21)

By requirement, an ammeter must have low resistance. The reason is that its insertion into circuit introduces an additional resistance in the circuit. So its resistance must be so small that it does not disturb the original current to be measured.

One necessary precaution must be taken before connecting an ammeter into a circuit. A positive mark (+) is written on one terminal of the ammeter. The positive terminal of the current supply must be connected to the positive terminal of the galvanometer. A mismatch in the connection may let the current to flow in opposite direction that may damage the galvanometer.

(C) Voltmeter

A voltmeter is a voltage-measuring instrument. It is essentially a galvanometer so modified to measure voltage to a desired range. The modification is accomplished by connecting a high resistance R_h in series with the galvanometer Fig. (16.22). The value of this resistance is several thousand ohms. Thus the resistance of a voltmeter is very high.

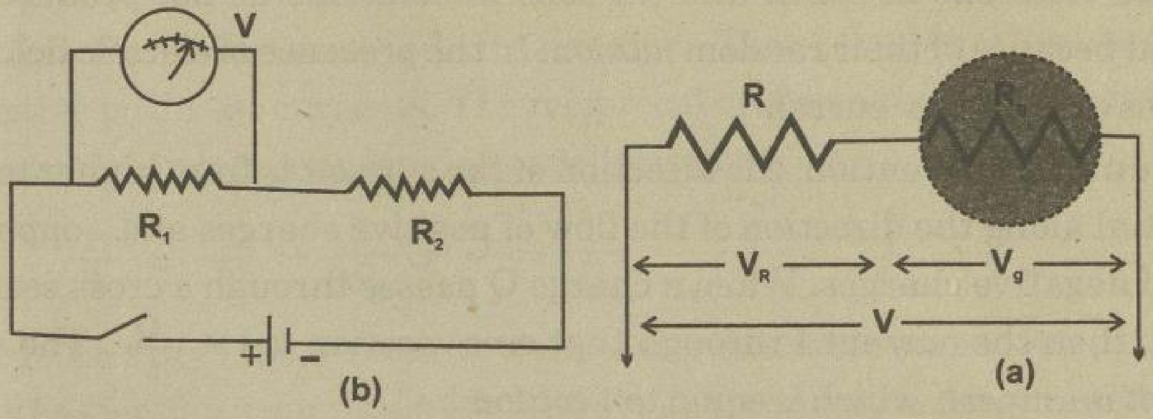


Fig. (16.22). (a)Conversion of galvanometer to voltmeter (b) use of voltmeter parallel

Voltmeter is always connected in parallel with the resistance across which the potential difference is to measured, Fig.(16.22 a). Higher the resistance of the voltmeter, more reliable would be its readings. If the resistance of the voltmeter is comparatively low, it will draw more current from the circuit. Due to this the potential difference across the resistance that was to be measured would drop. Therefore, a good voltmeter should have such a high resistance so that only a negligible current would pass through it.

When a voltmeter is connected in a circuit, care must be taken to connect its terminal marked positive (+) to that end of the resistance which is at higher potential

SUMMARY

Free Electrons: In metals, the valence electrons become free from their mother atoms. The free electrons move randomly within the metal like the molecules of a gas. They collide with one another and with the lattice ions.

Mobile Ions: Salts dissociate in solution to positive and negative ions. They move freely, rather sluggishly in solution. Sometimes gases are in ionized state. They contain positive and negatives In the absence of an electric field, the free electrons in solids and the ions in solutions do not produce a net current because of their random motion. In the presence of electric field these charges can produce current.

Current: By convention, the direction of the current is from higher to lower potential along the direction of the flow of positive charges and opposite to that of negative charges. When a charge Q passes through a cross section in time t, then the current I through that cross section is $I = \frac{Q}{t}$. The unit of current is ampere, which is equal to 1 coulomb s^{-1}.

Electric Cell and Electric Generators: An electric cell is a source of electrical energy. It is a device, which converts chemical energy to electrical energy. It separates positive and negative charges in a solution and pushes them to opposite electrodes. It maintains a PD between its two terminals. Two or more cells connected to support each other form a form battery. Every generator whether chemical, mechanical or nuclear maintains a PD between its positive and negative terminals.

Ohm's law: This law states that the current I in a conductor is directly proportional to the voltage applied across the conductor as long as the temperature is kept constant. Mathematically: $V = IR$, where R is the resistance of the conductor

Electric Resistance: Every conductor offers some resistance to the flow of current through it. The electrical resistance of a conductor is directly proportional to its length and inversely proportional to its cross sectional area. Every conductor has a specific resistance that depends on the nature of the conductor and temperature as well. The resistance of a conductor is one ohm if it allows one ampere current to pass through it when one volt voltage is applied across the ends of the conductor.

Electric circuit: The closed path for the flow of current is called circuit. There are two basic methods of connecting resistors in circuit: parallel and series combinations

Series Combination of Resistors: The resistors are connected end to end. There is only one path for the flow of current in the circuit. The equivalent resistance of the combination of resistors is: $R_1, R_2 + \ldots\ldots R_n = R$

Parallel Combination of Resistors: This combination provides alternative paths for currents. The reciprocal of the equivalent resistance of a number of resistors connected in parallel is given by

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}$$

Electric Energy is generated by a generator and is consumed in appliances such as heater, fan, radio, bulb etc. The available energy is determined by the voltage of the source and the current it can supply. If the voltage is V and the current is I then in time t the energy supplied or expended is given by W =Ivt.

Electric energy is measured in **joule or kilowatt-hour.**

Electric Power is the available electric per unit. It is given by P = IV. Its SI unit is watt and other useful units are kilowatt and horse power.

Joule's law The heat produced per second in a resistor R when a voltage V drives current I through it, is given by

$$P = I^2 R = \frac{V^2}{R}$$

Direct Current (DC) is the current that flows in only one direction.

Alternating current (A.C) is the current that changes its direction a number of times in one second.

Fuse is a small conducting wire that melts when a large current passes through it. When it melts, it breaks the electric circuit and thus saves electric appliances and home wiring from damages. After correcting the fault, a new fuse is inserted in the circuit.

Circuit Breaker is a modern device that breaks an electric circuit when the current exceeds the rated safety level. In case of a fault, a button moves upward and the current stops. After correcting the fault, the button is pressed down and the circuit is in order.

Safety measures: Electricity could be dangerous and even fatal. Safety measures are taken in handling electricity.

OBJECTIVE QUESTIONS

I. **Fill in the blanks.**

i. In the presence of external field, the _____ velocity of electrons is not zero.

ii. In a metallic solid _______ form a kind of a gas.

iii. In a closed electric circuit the motion of _______ and _______ ions contribute to the current.

iv. The conventional current is considered in the direction of the flow of ______ charges.

v. In electric cell, the positive ions of the electrolyte are pumped towards the _______ electrode.

vi. The resistance of a conductor depends on the following factors

(a) _______ (b) _______ (c) _______

vii. The resistance of a wire increases with increase in its ______ and decreases with increase in the _______ of the wire.

viii. The equivalent resistance of two resistors connected in series is given by $R =$ _________

ix. The equivalent resistance of two resistors R_1 and R_2 connected in parallel is given by $R =$ ______

x. In parallel combination of resistors, the ___ across each resistor is the same.

xi. The electrical energy expended in running an appliance depends on the following factors:

(a) _____ (b) _______ (c) _______

xii. The frequency of the A. C. electricity supplied to homes is _______ and the maximum voltage is _______.

xiii. The heat produced by A.C of maximum value I_{max} is $H =$ ______

xiv. D.C. always flows in _______ whereas A.C _______ its direction with time

xv. For large current, the _______ wire melts and _______ the circuit.

II. SHORT ANSWER QUESTIONS

i. Name five different conductors, which have plenty of free electrons.

ii. Distinguish between electrical conductors and insulators. Give three examples of each type.

iii. What are mobile ions. Give examples

iv. How does electrical conduction take place in liquids and gases. Explain

v. Define electric current.

vi. How does electric cell maintains constant current in a circuit? Explain

vii. Write a short note on conventional electric current.

viii. Compare the action of electric cell with a water pump.

ix. What is meant by electromotive force (e.m.f). Distinguish it from potential difference.

x. What do you mean by the electrical resistance of a conductor? Explain.

III . COMPREHENSIVE QUESTIONS

1. Define electric current. What is its unit? Explain the flow of current in a conductor.
2. State Ohm's law. To what kind of conductors does the law apply? Give examples where it is valid and where it is not invalid.
3. Define the electrical resistance of a conductor. Upon what factors, its value depends? Define the unit of resistance.
4. What is meant by electric circuit? Explain closed circuit and open circuit.
5. Two resistors R_1 andR_2 are connected in parallel. Derive the formula for their equivalent resistance. Describe the characteristic of this combination of resistors
6. Two resistors are connected in series. Derive the formula for their equivalent resistance. Describe the characteristics of the series combination of resistors.

7. Explain the concepts of electric energy and electric power. Discuss their units.
8. Write a comprehensive note on D.C and A. C.
9. Explain short-circuiting and overloading in electricity. Explain that short- circuiting is a special case of overloading.
10. What is a fuse? What is a circuit breaker? Write a note on their construction, method of connection and usefulness in a circuit.

NUMERICAL PROBLEMS

1. Charge of 8 coulomb passes through a cross section of a wire in 0.2sec. Find the current in the wire. **[40A]**
2. A current of 10^{-15}A passes through a cross section of a wire. How many electrons pass through the cross section in one second? **[6250]**
3. How much energy is required to move 12C of charge against 220V. **[2640J]**
4. A 12V battery is fixed in a car. Only one headlight of40W is lighted. How much current is passing through the head light? Find the resistance of the filament of the bulb. **[3.3A, 3.6Ω]**
5. A 120V voltage is connected across a resistor. A current of 4A is passing through it. Find the resistance. **[30 Ω]**
6. Using Ohm's law and Watt's law,
   Solve the following
   (a) $V=100V, I=2A,$ $R=$______, $P=$______
   (b) $V=5V, R=1K\Omega,$ $I=$______, $P=$______
   c) $I=1mA, R=50\Omega,$ $V=$______, $P=$______
   (d) $P=10W, I=2A,$ $V=$______, $R=$______
7. Resistance 6KΩ and resistance 12KΩ are connected in parallel. A battery of 6V is connected across the combination. Find the following quantities.

a) Equivalent resistance of the combination

b) Current passing through each resistor

c) Potential difference across each resistor

d) Time rate heat produced in each resistor

[4Ω, 1mA, 0.5mA, 6mJ, 3mJ]

8. An electric motor is driven by 220V and draws 11.0A current. Find the electrical energy expended by it in 5 hours. **[4.35×10^8 J]**

9. Two resistors of 2KΩ and 4KΩ are connected in series. The combination is connected 6V battery. Find the following quantities

a) The equivalent resistance of the combination **[6kΩ, 1mA, V,6V, 2mW, 4mW]**

b) Current passing through each resistor

c) The PD across each resistor

d) The time rate of heat produced in each resistor.

10. Fig. (16.1P) shows an electrical circuit. Find the resistance between the point A and B.

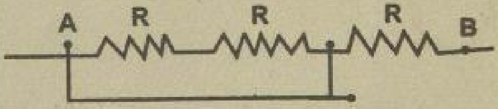


Fig. (16.1P)

11. Fig.(16.2P) is a circuit. Find the following

a) Equivalent resistance of the circuit

b) Current in each resistor

c) Total current in the circuit.

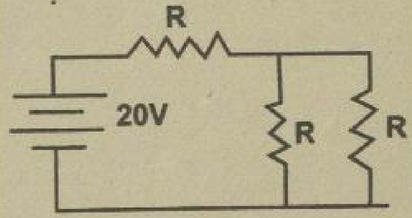


Fig. (16.2P)

12. Find the following in the circuit shown in Fig. (16.3P)

a) Total resistance of the circuit

b) total current in the circuit

c) Voltage across each resistor

d) Current in each circuit.

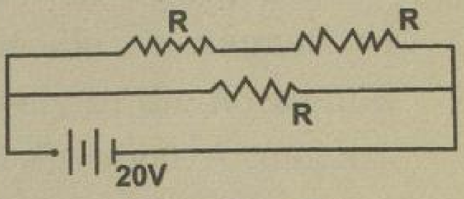


Fig. (16.3P)

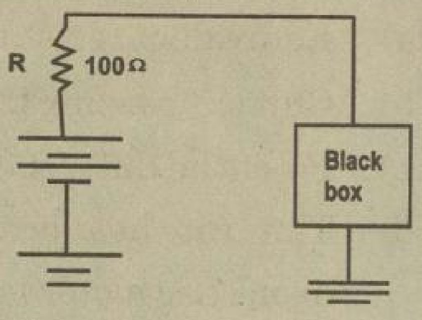


Fig. (16.4P)

13. In Fig. (16.4P) a current of 10.5 A is passing through the "box" representing various appliances:
   a) What is the potential at point A
   b) The resistance of the "box".

14. Five bulbs, each of 100W are lit in a house for 5 hours daily. Two fans, each of 75 watt, are working daily for 8hr. Electric iron of 500 W is used daily for one hour. A 100-watt TV is on for 3 hours daily. The rate of one unit of electricity is Rs 0.75. Find the total monthly bill of the house. **[Rs. 101.00]**

Chapter 17

MAGNETISM AND ELECTROMAGNEISM

In this chapter you will study

- Magnetic field: its intensity and direction
- Discovery of electromagnetism
- The magnetic field of a straight current carrying wire
- The right-hand rule of electromagnetism
- The magnetic field of a circular coil and of solenoid
- Magnetic force on a moving charge
- Direct current motor
- Electromagnetic induction
- Alternating current generator
- Mutual induction and self induction
- Transformer

17.1. Magnet and Magnetic Field

Magnet

You are familiar with the interesting properties of a magnet. A magnet attracts bits of iron. A freely suspended magnet always points in north-south direction. The end of the magnet pointing towards north is called the N-pole while the other end is called S-pole. Like poles of two magnets repel while unlike poles attract each other. A magnetic compass needle is a magnetized iron needle, which is so pivoted that it can turn freely in the horizontal plane. This needle comes to rest along the north-south direction. A compass needle is often used to investigate a magnetic field.

The earth behaves like a bar magnet. The magnetic S-pole of this bar magnet is at the geographic North Pole of the earth. The magnetic N-pole of the earth's bar magnet is at its geographic South Pole. However, note that the magnetic and geographic poles do not coincide; they are somewhat away from one another.

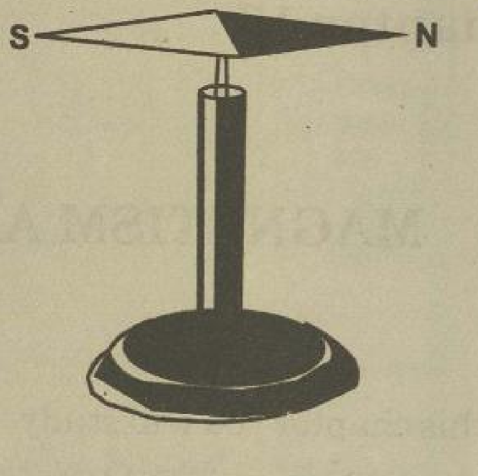


Fig. (17.1) A simple magnetic compass Needle

Magnetic Field

Every magnet effects every thing made of iron and placed near it. ***The space surrounding a magnet in which its magnetic effect is felt is called magnetic field.*** In general, any region in which magnetic effect is felt is called a magnetic field. Like gravitational and electro-static fields, the magnetic field cannot be seen but it can be traced by means of a small test magnet such as the compass needle. The magnitude and the direction of a magnetic field at any field point is determined by the force the field exerts on a test magnet placed at that point. Magnetic field is represented by lines of force. The magnetic field of a bar magnet, as represented by lines of force is shown in Fig. (17.2).

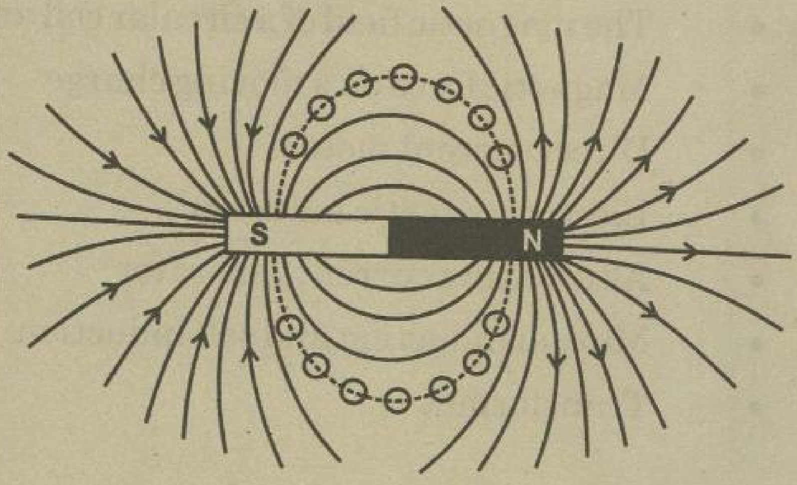


Fig.(17.2) Magnetic field of a bar magnet as represented by magnetic lines of force

17.2. Electromagnetism

Apparently, electrical and magnetic effects seem to be different and unrelated. The fact is that both the effects are produced by electric charge. On the basis of experiments we know that static charge produces electrostatic effects whereas moving charge, that is, current produces both electric and magnetic effects. First of all, Oersted discovered in 1820 that, besides electric field, a current in a wire also produces a magnetic field around itself. In the next three sections you will come to know that the nature of the magnetic field depends on the current and the geometrical shape of the current carrying conductor.

17.3. Magnetic Field of a Straight Current Carrying Wire

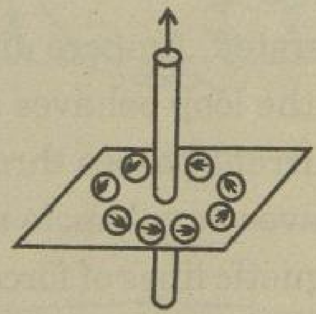


Fig.(17.3) Magnetic field lined due to current in a straight wire

Pass vertically a straight long wire through a hole in a piece of cardboard. Connect the ends of the wire through a switch to the terminals of a battery as shown in Fig. (17.3). Sprinkle some iron filings on the cardboard. Turn on the switch and let current pass through the wire. Tap the cardboard gently. You will see that the iron filings set in a series of concentric circles with the wire as centre. It is clear that the magnetic field is formed due to the current in the wire.

The magnetic field lines of a current in a straight wire are circular lines in a plane perpendicular to the wire.

The magnetic field of this current can also be traced by means of a magnetic compass. An advantage in this method is that at every point, the direction of the magnetic field is also determined. A compass needle is placed near the wire and the direction indicated by its north pole is noted. The lines of force are clockwise for the current flowing downward. Conversely, the lines of force are counterclockwise for upward current.

Right Hand Rule

There exists a rule that relates the direction of the magnetic lines of force around a wire with the direction of current flowing through it. This is known as right hand rule. The rule states that if the current-carrying wire is grasped by the right hand with the thumb in the direction of the current, the fingers encircle the wire in the direction of the field, Fig. (17.4).

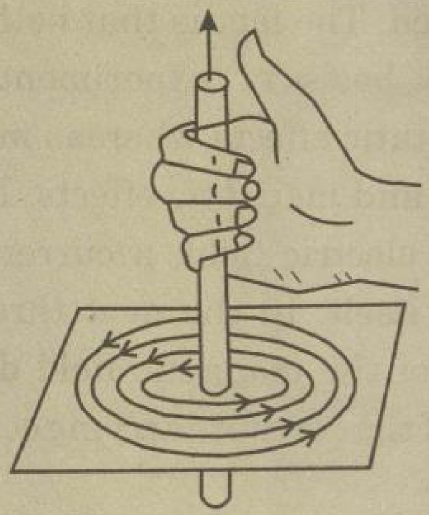


Fig. (17.4) Illustration of the RH-rule

17.4 Magnetic Field of Circular Current

After Oersted, Ampere discovered that when current passes through a loop of wire, the loop behaves as a magnet. A circular coil is shown in Fig.(17.5). When current passes through the coil, it becomes a magnet. One face of the coil behaves as a N-pole and the other face behaves as a S-pole, Fig.(17.5) The magnetic lines of force are shown in the figure. In the central region, the lines are straight, parallel and normal to the plane of the coil. The magnetic field in the central region is uniform. Away from the centre, the field is not uniform. It should be noted that the magnetic field of the current in a circular coil is determined by the right hand rule.

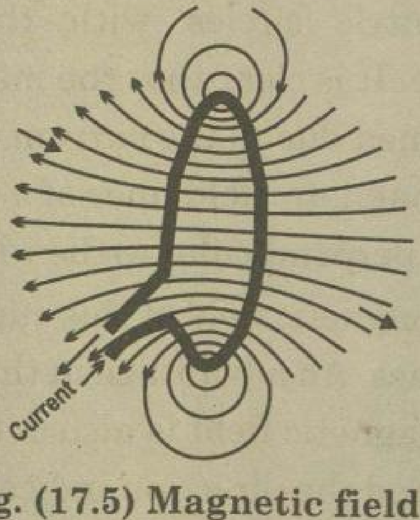


Fig. (17.5) Magnetic field of circular coil

A circular coil may consist of a single turn or several concentric and closely wound turns. A coil of N turns produces N times stronger field at the centre of the coil. The field in the central region can also be increased by reducing the radius of the coil as well as by increasing the current.

17.5 Magnetic Field of Solenoidal Current

A solenoid is a closely wound cylindrical coil of insulated wire. Fig.(17.6) shows the magnetic lines of force produced by direct current through solenoid. The field due to solenoidal current is, in fact, the sum of the fields due to current in each circular turn of the solenoid.. Using the right hand rule to each turn of the solenoid, you can find that inside the coil the magnetic lines of force of all the turns are in the same direction. Outside the solenoid, there is no definite order in the lines of force.

One special characteristic of the magnetic field of solenoid is that the field lines emerge out of the one end N of the solenoid. After circulating around, the lines enter into the solenoid through the other end S. Within the solenoid, the field lines are in the same direction and are parallel to the axis of the solenoid. It can be seen that the field lines pattern of a current carrying solenoid resembles the field pattern of a bar magnet shown in Fig.(17.6). On the basis of this resemblance, we can say that one end of the solenoid behaves like a north pole and the other like a south pole.

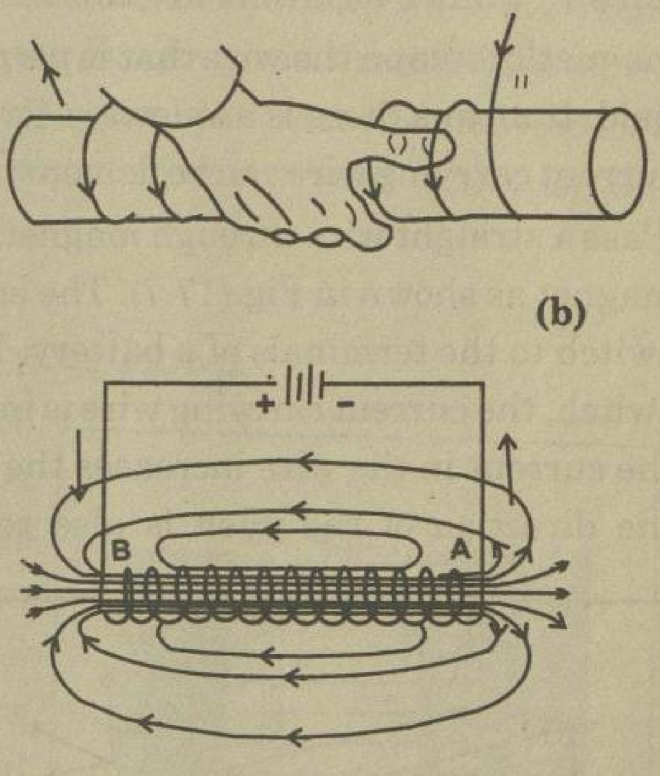


Fig.(17.6) (a)

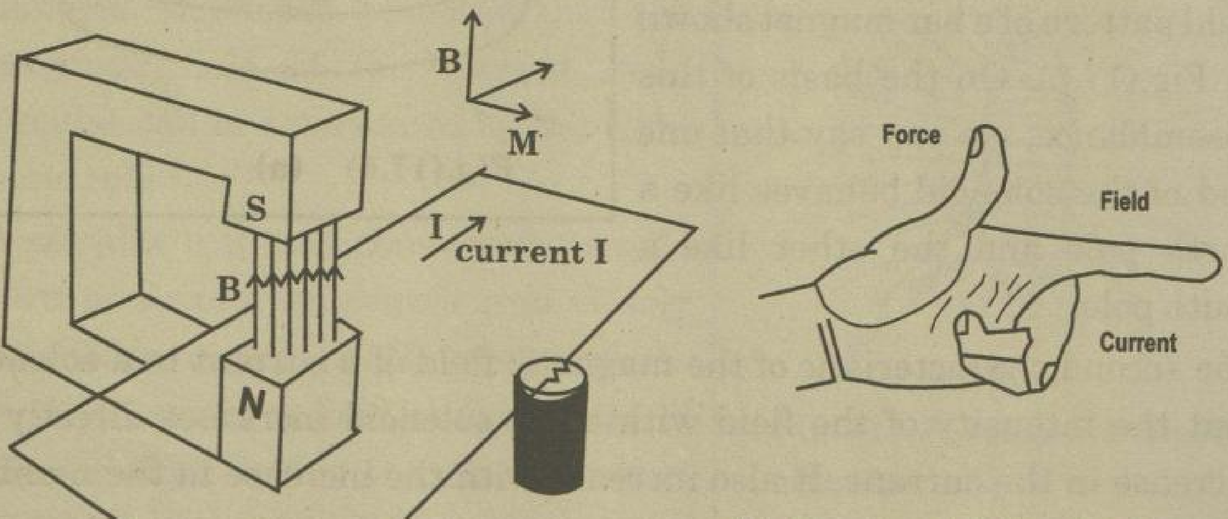
The second characteristic of the magnetic field of a current in a solenoid is that the intensity of the field within the solenoid increases directly with increase in the current. It also increase with the increase in the number of turns of the solenoid.

The polarity of the magnet depends upon the direction of the current passing through the solenoid. The polarity can be determined by means of a compass needle. However, it can be easily determined by the following right hand grasp rule: Grasp the solenoid in the right hand by curling the fingers in the direction of the current, the stretched thumb would indicate towards the north pole, Fig.(17.6b)

17.6 Magnetic Force on a Current Carrying Wire

Current in a conducting wire is due to large number of free electrons drifting along the same direction with a certain drift velocity v. When such a wire is placed in a magnetic field B then every electron is acted upon by a magnetic force F_m. Since electrons are confined inside the wire, therefore, there is a magnetic force on the wire that is perpendicular to the wire and the magnetic field. It means there is a sideways force on the wire. The magnetic force on a current carrying wire can be demonstrated by the following experiment.

Pass a straight wire through magnetic field between the poles of a U-shaped magnet as shown in Fig.(17.7). The ends of the wire are connected through a switch to the terminals of a battery. You can observe that by turning on the switch, the current carrying wire is immediately pushed to a side. Increasing the current in the wire increases the push. Reverse the current in the wire, the direction of the push is also reversed.. Reverse the direction of the



(b) Fleming left hand rule

Fig.(17.7). (a) Magnetic force on a current carrying wire magnetic field by exchanging the positions of the N- and S-pole. The magnetic force on the wire is reversed. On the basis of this type of experiments, we find the following for the current carrying wire placed in a magnetic field.

The magnetic force F_m on a wire of length L carrying current I and placed in perpendicular orientation to a magnetic field of intensity B is given by:

$$F_m = BIL \qquad (B \perp L)$$

Fleming Left Hand Rule

Stretch the thumb, forefinger and the middle finger of your left hand such that they are mutually perpendicular. Point the ***F****orefinger in the direction of the* ***F****ield, the m****I****ddle finger in the direction of the current* ***I****, then the thu****M****mb will point in the direction of the* ***M****otion of the current carrying conductor.* See Fig.(17.7b).

17.7 Torque on a Current Carrying Loop

Consider a rectangular coil ABCD, which is placed in the magnetic field of a magnet as shown in Fig. (17.8). The coil is so suspended that it can rotate freely about its axis. Now we will show that the coil will rotate about its axis when current is passed through the coil. In the initial position shown in the figure, the sides AB and CD of the coil are perpendicular to the magnetic field. The sides BC and DA are parallel to the field. Let the ends of the coil are now connected to the terminals of a battery. A current would start flowing through the coil as shown in the figure. The direction of the current in the sides BC and DA is parallel to the magnetic field. Thus no force would act on these sides In sides AB and CD the direction of current is at right angle to the field. So, force would act on these sides. According to Lorentz right hand

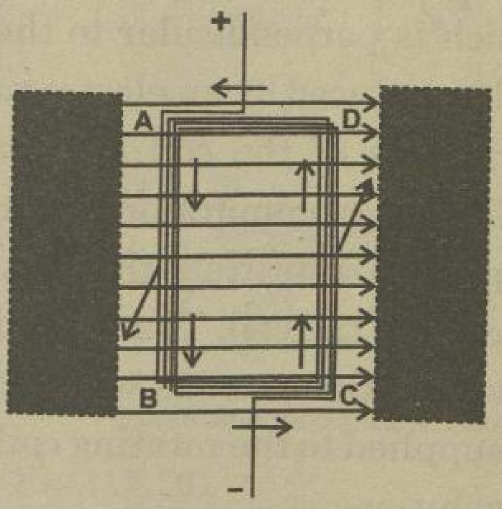


Fig.(17.8). Torque on a current carrying loop.

rule, the forces acting on sides AB and CD would act horizontally in opposite directions. See Fig.(17.9) The magnitude of each of these forces is

$$F_m = ILB \qquad (B \perp L) \qquad (17.1)$$

Under the action of these two equal but anti-parallel forces, a couple would act on the coil. The coil would start rotating.

The general principle is that when current is passed through a coil suspended in a magnetic field, a torque is exerted on the coil.

17.8. D. C. Motor

An electric motor is a device, which converts electrical energy to mechanical energy. The underlying **principle** of an electric motor is that ***a current carrying coil in a magnetic field is acted upon by a torque, which tends to rotate the coil***.

An electric motor consists of an ***armature,*** which is a coil of N turns wound on an iron core, Fig. (17.9). The armature can rotate about an axis, which is perpendicular to the magnetic field produced by an electromagnet. The terminals of the coil are connected to split-ring (commutator) R. Brushes b, b′ supply current from the battery or D.C supply to the coil. The split-ring system reverses the sense in which the current is supplied to the rotating coil every half revolution.

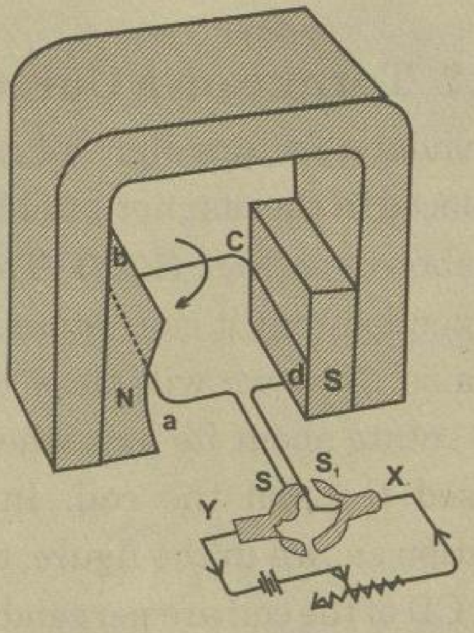


Fig.(17.9) D. C. motor

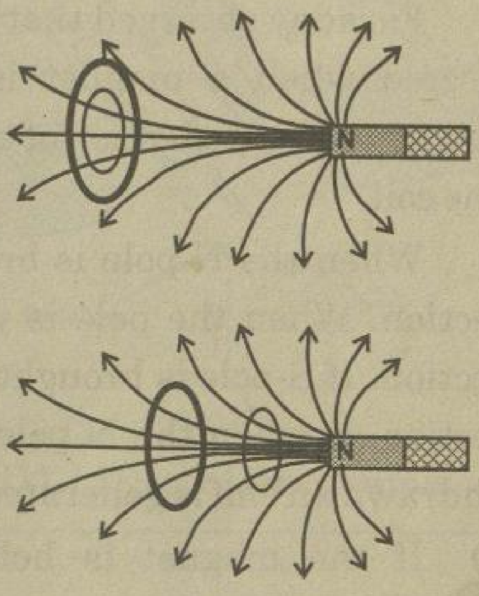
When current I is passed in the armature coils then the coil is acted upon by a torque until the plane of the coil is perpendicular to the field, where torque becomes zero. At this instant the split-ring system reverses the direction of the current and the armature continues to rotate. The rotating armature provides mechanical power.

There are various modifications of electric motors but the basic principle is

Electric motor is use as the basic device for converting electrical energy to mechanical energy. The applications are electric fan, water pumps, electric drills and washing machines. Electric motors are used in communications devices, telephone, television, radar and tape recorders.

17.9. Electromagnetic Induction

The discovery by Oersted in 1819 that a current gives rise to a magnetic field led to the search that a magnetic field might produce a current. Such a phenomenon was discovered in 1830 by J.Henry in America. A few months later M. Faraday in England also discovered it, independently. A magnetic field is represented by lines of force. If a coil is placed in the magnetic field of a bar magnet, some of the lines of force will pass through its face. If the coil is far away from the coil, only a few lines of force will pass through it. On the other hand , if the coil is close to the magnet, a large number of lines of force will pass through it, Fig.(17.10) The number of lines of force passing through any surface is known as magnetic flux through that surface.



Electromagnetic Induction

Fig.(17.10)

Faraday found that if the magnetic flux through a closed loop of wire is changed, a current is found to flow in the wire. Since current is caused to flow by a source of e,m.f. , the changing magnetic flux through the loop must be the cause of induced e.m.f. in the loop. This induced e.m.f. produces current in the closed loop. This phenomenon is called electromagnetic induction. Typical experiments that led to the discovery of electromagnetic induction are described below.

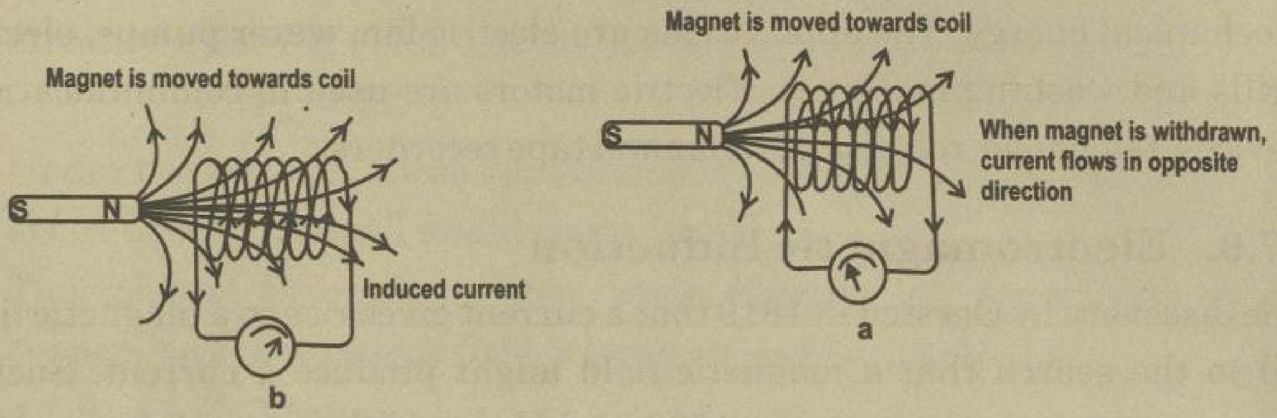

Magnet is moved towards coil
S
N
Induced current
b
Magnet is moved towards coil
S
N
When magnet is withdrawn, current flows in opposite direction
a

Fig.(17. 11). Galvanometer deflects, while the magnet is moving relative to the coil

(i) Faraday observed that a galvanometer connected to the ends of a coil deflected when a magnet is **moved toward or away** from the coil, Fig.(17.11). The deflection of the galvanometer shows that a current is set up in the coil.

(ii) When the N-pole is brought near the coil, the current flows in one direction. When the pole is withdrawn, the current flows in the opposite direction. If S-pole is brought toward the coil, the deflection is in the same direction as when the N-pole is withdrawn. Similarly, when the S-pole is withdrawn an emf is generated in the coil.

(iii) If the magnet is held stationary with respect to the coil, the galvanometer needle does not deflect.

(iv) Similar results will be obtained if the magnet is held stationary and the coil is moved towards or away from the magnet.

So it is the **relative motion** of the magnet and the coil that causes the deflection of the galvanometer. The relative motion changes the magnetic flux emerging from the pole of the magnet and linking the coil.

Electromagnetic Induction: ***The phenomenon, that whenever the magnetic flux linking a closed loop is changed there is an emf induced in the loop, is called electromagnetic induction.*** The induced emf lasts as long as the flux is changing. The current so produced in the loop is called ***induced current.***

All the experimental facts mentioned above are formulated in a single law, called Faraday's law of electromagnetic induction. ***The law states that whenever the magnetic flux linking a circuit is changed, there is an induced emf in the circuit. The value of the induced emf is proportional to the time rate of change of the magnetic flux through the circuit.***

17.10 A. C. Generator

A generator is a device, which converts mechanical energy into electrical energy. In principle it is based on **electromagnetic induction:** rotation of a coil in a magnetic field undergoes a change of magnetic flux linking the coil and thereby an emf is ipnduced in the rotating coil.

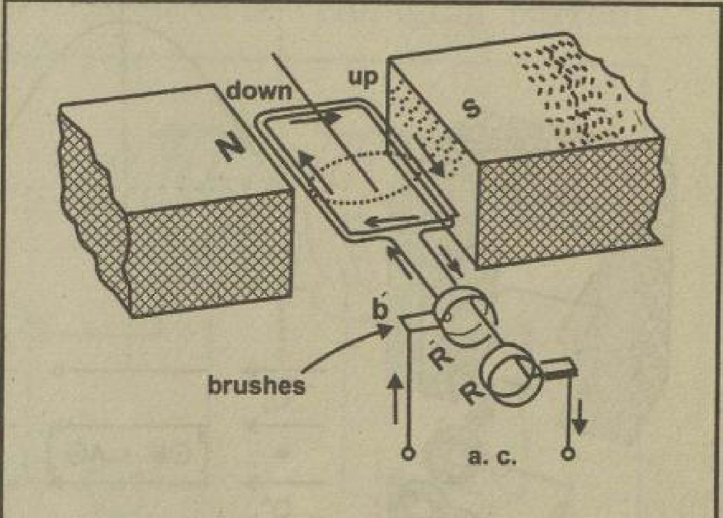


Fig. (17.12) A.C. Genrarator

A generator consists of a rectangular coil of N turns, which are wound on an iron core. The assembly of coil plus cylinder is called **armature.** A simplified figure of the generator is shown in Fig. (17.12). The armature can rotate about an axis OO'. The axis is perpendicular to a uniform magnetic field of flux intensity B. The terminals of the coil are connected to slip rings R, R'. The rings, connected with OO', rotate with the coil and are insulated from each other. Brushes b, b' slide along the rings and connect the coil to the external circuit.

The emf generated in the coil can be understood from the following description.

Fig.(17.13) shows the emf that is generated during one complete rotation of the coil. Suppose in the beginning the coil is vertical with its side A upward and side B downward as shown in Fig.(17.14a). In this figure, the sides A and B have been shown by their vertical sections. In this position the sides A and B are moving parallel to the field due to which the rate of change of flux through the coil is zero. So, according to Faraday's law, the emf induced in the coil is zero ,Fig.(17.14a, point O). After completing one quarter of the rotation the position of the coil is shown in Fig.(17.14b). At this instant both the sides A and B are moving at right angle to the field and the rate of change of flux through the coil is maximum, Fig. (17.14b. point 1/4).

Figure of ac-generator and the sine curve

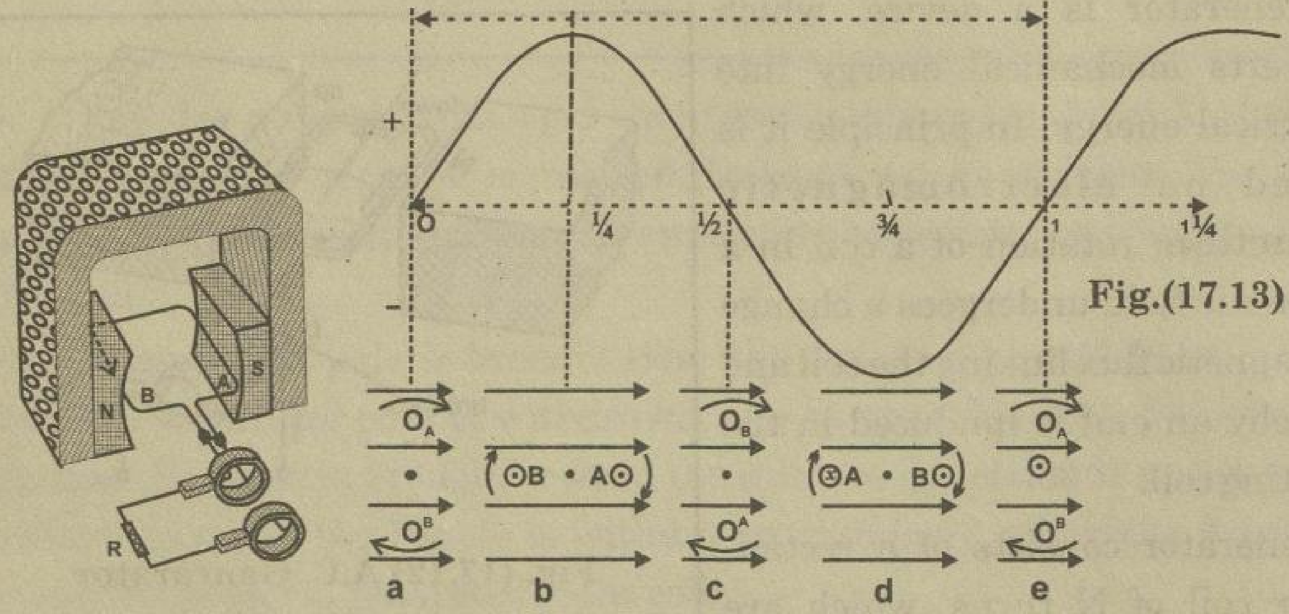


Fig.(17.13)

Fig.(17.14)

After one half rotation of the coil, the positions of side A and B is shown in Fig. (17.14c,.point 1/2) In this position, the side A is located downward and side B upward. As the coil rotates, the direction of induced emf changes. After three quarter of its rotation, the coil assumes the position shown in Fig.(17.14 d). At this instant, the emf is at its maximum value but its direction is opposite to that of Fig.(17. 14b,point 1/4)

The position of the coil after one complete rotation is shown in Fig.(17.14e). Now the emf is again zero because this position is the same as shown in

Fig.(17.14a). Henceforth, the coil starts its next rotation and the next cycle of the induced emf starts. In this way, the rotation of the coil in a magnetic field generates an alternating induced emf.

The uses of A. C. generator are countless. Whenever electrical energy is utilized, there is invariably some where an A.C-generator supplying the energy. A. C. generators are used to convert the kinetic energy of waterfalls to electrical energy. Huge A.C-generators are installed at Tarbela, Mangla and Warsak etc. In petrol and diesel operated ac-generators, the chemical energy is ultimately converted to electrical energy.

17.11. Mutual Induction

According to the principle of electromagnetic induction, a changing current in one coil can produce an induced emf in a neighbouring coil. So starting, stopping or varying current in a primary coil A will produce emf in the secondart coil B. See Fig.(17.15). The current in the coil B lasts only as long as the current in the coil A is changing. ***The effect which produces emf in one circuit due to a changing current in another neighbouring circuit is called mutual induction.***

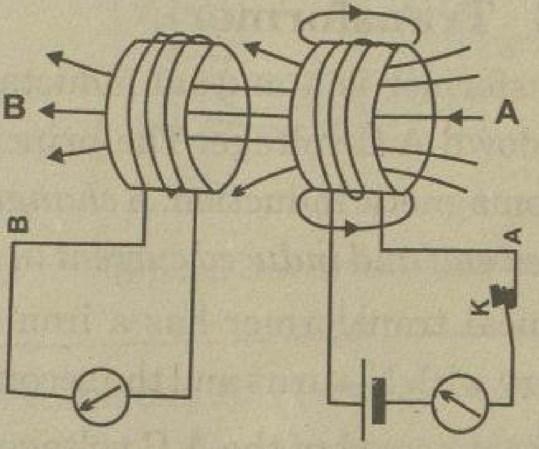


Fig. (17.15) When current in the primary coil changes, induced emf is produced in the secondary coil

17.12. Self Inductance

A coil of wire can induce emf in itself, Fig.(17.16). This follows from the fact that when a current flows in a coil, the current causes magnetic flux through the same coil. If the current changes the flux also changes and an emf is induced in the coil. The effect that a changing current in a circuit or coil produces an emf in the same circuit or coil is called self-induction.

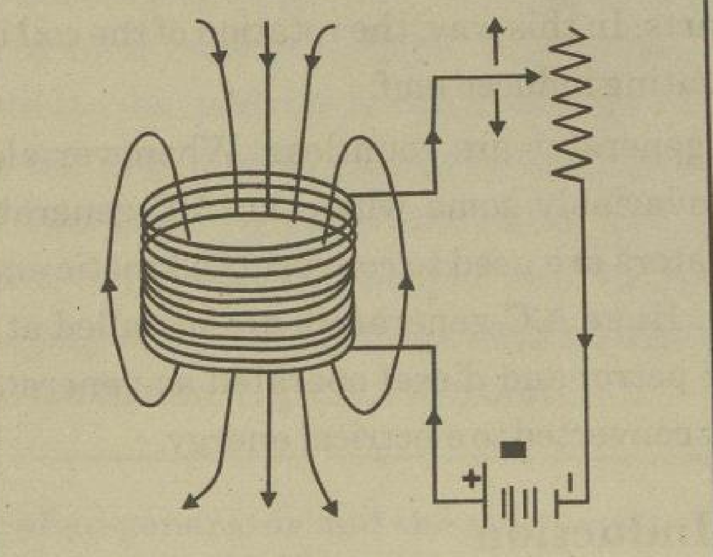


Fig.(17.16) Self inductance

17.13 Transformer

A transformer is a mutual inductance electrical device, which steps up or steps down A.C-voltage. The principle on which a transformer operates is electromagnetic induction: *A changing current in a primary coil can cause an induced emf and induced current in a neighboring secondary coil.*

A typical transformer has a iron core on which two coils are wound, the primary with N_p turns and the secondary with N_s turns. The primary coil is connected to the A.C voltage V_p and the output voltage V_s is obtained across the terminals of the secondary, Fig.(17.17).

The A.C in the primary coil produces a changing magnetic flux in the iron core. As the flux lines follow the iron core, the lines circle through as shown in Fig. (17.18). Hence the flux through the primary and the secondary coils is the same. The changing flux through the secondary coil gives rise to an induced emf V_s in the secondary coil.

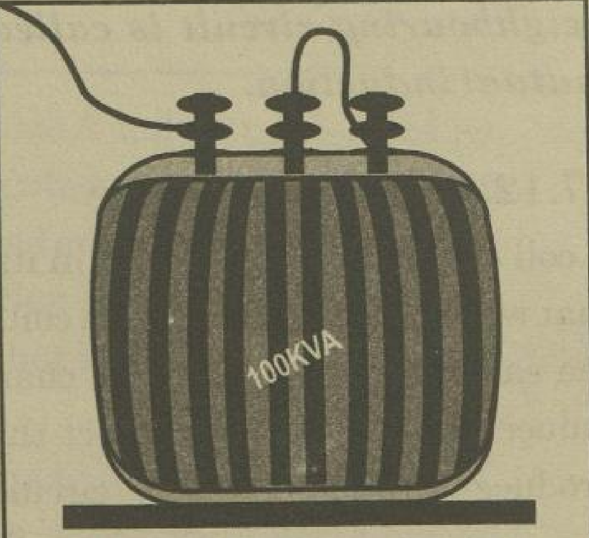


Fig. (17.17) Transformer

In most transformers, the resistance of the coils is negligible. The induced emf V_p in the primary is equal to the input driving voltage. It can be easily proved that the voltages and number of turns in the primary and secondary coils are related as follows:

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

A transformer that raises the input voltage V_p to a higher voltage V_s has $N_s > N_p$ and is called a *step-up* transformer. The reverse case in which $V_s < V_p$ has $N_p > N_s$ is called a *step-down* transformer. Fig.(17.18).

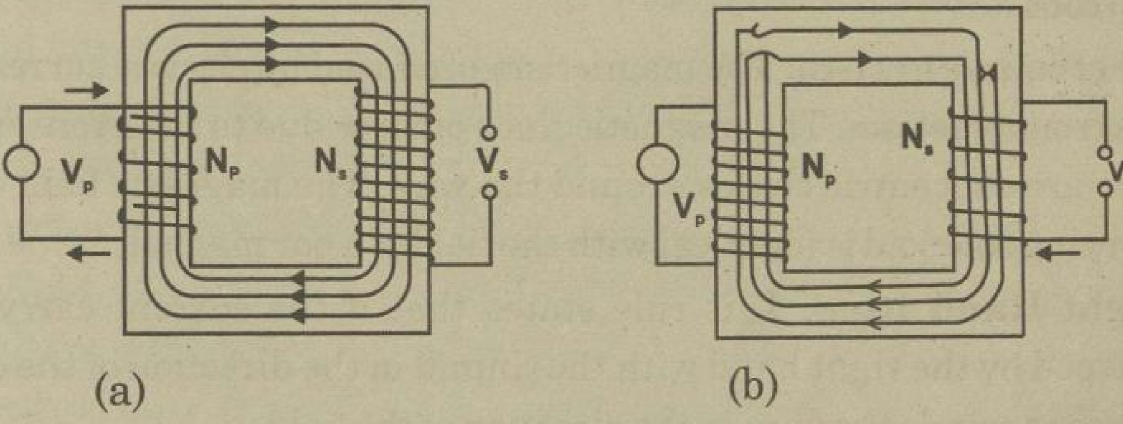


Fig.(17.18) (a) step-up transformer (b)step-down transformer

Transformer is used for changing the voltage in A.C circuits. It is used in the design of circuits for communication, in radio, television, telephony and radar etc.

The most important use of transformers is in the transmission and distribution of electric power from the distant generating plant to industrial and household users. At the generating end, electrical energy is transformed into high voltage and low current. This minimizes the I^2R heating loss in the transmission line. At the user end, the voltage is stepped down to say 220 volts. The common doorbell requires a voltage of 9V, and a transformer is used to obtain this voltage from the usual supply of 220V.

SUMMARY

Magnet: A magnet has two poles: N-pole and S-pole. A single isolated pole cannot be separated. Like poles of two magnets repel while unlike poles attract each other

Magnetic field: Any region in which magnetic effect is felt by a test magnet is called a magnetic field. At any field point, the magnitude and the direction of a magnetic field are determined by the force the field exerts on a test magnet at that point. A magnetic field is represented by magnetic lines of force. Magnetic lines of force can pass easily through magnetic iron, nickel and cobalt.

Electromagnetism: The magnetism produced by electric currents is called electromagnetism. The magnetic lines of force due to a current in a straight wire are concentric circles around the wire. The magnetic field of a current carrying solenoid is identical with the field of a bar magnet.

Right Hand Rule: This rule states that if the current carrying wire is grasped by the right hand with the thumb in the direction of the current, the fingers encircle the wire in the direction of the field.

Electromagnet: If soft iron is inserted in the core of a coil, the magnet so formed is called electromagnet. Its strength is increased by increasing the current and the number of turns of the coil.

Magnetic Force: Magnetic field exerts no force on a static charge. It does exert force on a moving charge. The magnetic force Fm exerted by a magnetic field of strength B on a charge q moving with velocity v is given by:

$$F_m = q\,v\,B\sin\theta$$

where θ is the angle between $\vec{B}$ and $\vec{v}$. This kind of force exerted by on a moving charge or current is called magnetic force. There is no magnetic force on a charge moving parallel to

Force on a Current Carrying Wire: The magnetic force on a straight wire of length L, carrying current I when placed in a magnetic field of strength B is:

$F_m = BIL$ $(\vec{B} \perp \vec{L})$**Electromagnetic**

Induction: Whenever, the magnetic flux linking a closed loop is changed there is an emf induced in the loop. This phenomenon is called electromagnetic induction.

Faraday's law of electromagnetic induction: The law states that whenever the magnetic flux linking a circuit is changed, there is an induced emf in the circuit. The value of the induced emf is proportional to the time rate of change of the magnetic flux through the circuit.

An electric motor is a device, which converts electrical energy to mechanical energy. The underlying principle of an electric motor is that a current carrying coil in a magnetic field is acted upon by a torque. This torque tends to rotate the coil.

An A. C. generator consists of coil. When this coil is made to rotate in a magnetic field, the magnetic flux through it continuously changes due to which an alternating voltage is induced in it.

Mutual induction: If the change of the current in a circuit induces current in another circuit, this phenomenon is known as mutual induction.

Self-induction: If the current through a coil or circuit changes and this change induces an emf in the circuit itself, the phenomenon is known as self-induction.

Transformer is an electrical device, which is used to increase or decrease the value of an alternating voltage.

OBJECTIVE QUESTIONS

1. **Encircle the correct answer.**

i. Permanent magnet is used in

(a) electromagnet (b) telephone (c) electric bell

ii. Temporary magnet is used in

(a) telephone (b) electric bell (c) watch iii A bar magnet is cut in the middle. There appears on the cut ends

(a) Two like poles (b) Two opposite poles (c) no poles

iv. The magnetic force on a current carrying wire is perpendicular to

(a) Current only (b) Magnetic field only

(c) both current and magnetic field

v. The direction of the magnetic field at any place is the same in which

(a) a charge moves (b) magnet moves

(c) the direction from south to north of a test magnet

2. Fill in the blanks

i. A magnet has _____ poles. A single isolated pole ______ exist.

ii. Permanent magnets are used in the following devices:

(a) ________ (b) _________ (c) _________

iii. Electric current produces electrical as well as _______ effects.

iv. The magnetic field inside a current carrying coil depends on the following factors:

(a) ___________ (b) ___________ (c) ____________

v. The orbital electrons of an atom are equivalent to a ____ loop and gives rise to ________ properties.

vi. The magnetic force of electromagnet depends on the following factors:

(a) __________ (b) ____________ (c) _____________

vii. Electromagnet is used in the following devices:

(a) _____________ (b) _____________ (c) ____________

viii. Magnetic field does not exert force on _______ charge, but it does exert force on a _________ charge.

ix. The magnetic force on a current carrying coil depends on the following factors:

(a) __________ (b) ___________ (c) ____________

x. The magnetic force on a current carrying wire placed in a magnetic field is ________ to the field and ________ to the wire.

xi. A transformer is used to ________ up voltage.

xii. A D.C. motor converts ________ energy to ________ energy.

xiii. A. C. generator converts ________ energy to ________ energy.

COMPREHENSIVE QUESTIONS

1. Write at least four properties of a magnet.
2. Define magnetic field. How is its intensity and direction specified?
3. What are magnetic lines of force? Represent the field pattern of a bar magnet by lines of force.
4. What do you mean by electromagnetism? Write a note on it.
5. Represent diagrammatically the magnetic field of a long straight wire.
6. State the first right hand rule of electromagnetism. Illustrate it by a diagram.
7. Write a note on atomic magnetism.
8. What kind of force acts on a current carrying wire placed in a magnetic field? Explain it on the basis of the motion of electrons.
9. State Lorentz' right hand rule for $\vec{B}$, I and $\vec{L}$.
10. Illustrate by a diagram, the magnetic field of a current carrying solenoid. Identify the polarity of the magnet so formed. Discuss the intensity and the direction of the field.
11. Fig. (17.1P) shows the cross section of a straight current carrying wire. The arrows represent the magnetic field in which the wire is placed. Indicate the force acting on the wire by an arrow sign.

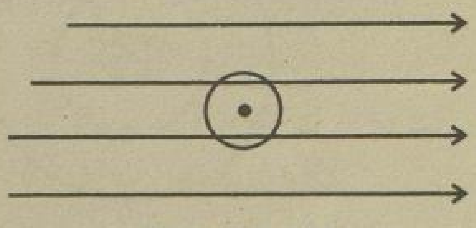


Fig. 17.1P

12. Fig.(17.2P) shows a current carrying wire suspended in between the pole pieces of a magnet. The arrows show the direction of the current flow through the coil. Explain whether the coil would rotate in clockwise or counter-clockwise direction.

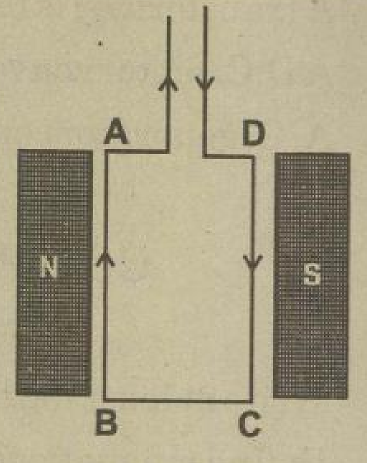


Fig.(17.2P)

13. Show by an experiment that a current can be induced in a coil by a magnet. What are the factors upon which the value of this current would depend?
14. Write notes on mutual induction and self induction.
15. Describe the principle, construction, working and uses of the following electrical devices.

    (a) D. C. Motor (b) A. C. Generator (c) Transformer
16. A step-down transformer changes 220 V alternating voltage to 6V alternating voltage. If the number of turns in the primary coil is 1000, find the number of turns in its primary. **[240]**

Chapter 18

NUCLEAR PHYSICS

In this chapter you will study

- The structure of atomic nucleus
- Radioactivity: natural and artificial
- Emission of α, β, γ, radiation from the nucleus
- Half-life of radioactive element
- Isotopes and uses of radio isotopes
- Einstein mass-energy equation
- Nuclear fission and nuclear fusion
- Radiation hazards and safety measures

18.1. Atomic Structure

You know that **atom** has two parts; the central massive and dense part called the **nucleus** and the outer lighter part in which the **electrons** cloud around the nucleus. Nucleus is almost spherical and its diameter is about 10^{-14} m. The diameter of an atom is about 10^{-10} m. This means that the diameter of the atom is about ten thousand times that of the nucleus.

The nucleus is composed of **protons** and **neutrons.** The charge on proton is plus **1.6×10^{-19} coulomb**. There is no charge on neutron. Therefore, the nucleus has a positive charge. Electron has a negative charge equal in magnitude to the charge on a proton. In a normal state an atom is

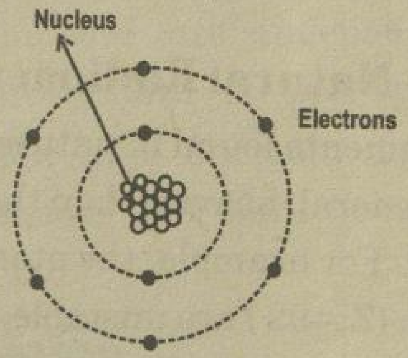


Fig.(18.1) The nucleus of an atom consists of protons and neutrons Electrons revolve around the nucleus.

electrically neutral. The number of electrons in an atom is equal to the number of protons in the nucleus. This is why, that on the whole, an atom has no net charge.

The mass of a protons is almost equal to the mass of a neutron and each mass is found to be **1.67×10^{-31} kg.** The number of protons and the number of neutrons in a nucleus are almost equal. Protons or neutrons in a nucleus are called **nucleons.** The mass of a nucleon is about 1836 times the mass of an electron. Therefore, for all practical purposes, the mass of an atom is equal to the sum of the masses of its nucleons.

The number of protons in the atoms of different elements is different. This number is represented by Z and is called the **atomic number** or the charge number of the atom.

The number of neutrons in the nucleus of an atom is represented by N. The sum of the number of protons and the number of neutrons, Z + N, is known as the **mass number** A. The number of nucleons is equal to A. The atomic nucleus of an element having chemical symbol X, atomic number Z and mass number A, is written as $_ZX^A$ For example, the Uranium nucleus has the atomic number Z = 92, mass number A = 235. It is symbolically written as $_{92}U^{235}$. Similarly, Helium has the chemical symbol He, atomic number Z = 2 and mass number A=4. It is written as $_2He^4$. There is no charge on neutron and is symbolically represented by $_0n^1$.

18.2 Natural Radioactivity.

Some elements found in nature are unstable. The atoms of these elements are, in general, heavier than the atomic lead (Pb).The atomic number of lead is Z = 82. For example, the atoms of polonium (Z = 84), radium (Z = 88) and uranium (Z = 92) are unstable. These elements emit, spontaneously, special kind of energetic radiation. This phenomenon is called radioactivity. The elements, which exhibit radioactivity, are called radioactive elements.

Radioactivity is a process as a result of which an element of one kind of atoms gradually changes to the atoms of another kind of atoms. Radioactivity is a process, which cannot be reversed. This characteristic property of heavier atom is a natural as well as accidental. The phenomenon is, therefore, called natural radioactivity. Presently, artificial radioactive elements have been prepared. For an artificially prepared radioactive element, it is not necessary that $Z \geq 82$. The activity shown by artificially prepared elements is known as artificial radioactivity.

In 1896, a French scientist, Henry Bequerel discovered radioactivity. He was studying a fluorescent salt of uranium and wanted to test the fluorescent radiation emitted by the salt might be X-rays, which were recently discovered by Rontgen in 1895. He kept the fluorescent compound in a paper and placed in a drawer where there were already placed some photographic plate covered in a black paper. After a few days, he found that the photographic plates carry some impressions. From this observation, he concluded that the uranium salt, in the absence of sunlight, emits radiation which, pass through the wrapping paper and affect the photographic plates. In order to test his conclusion, he performed many experiments. He placed a sheet of glass and aluminium foils etc. between the uranium salt and the photographic plate and obtained the earlier result: the photographic plate is affected by radiation from uranium salt. From these experiments, Bequrel discovered the uranium element emitted energetic radiation that would penetrate through several thicknesses of thick black paper and affect photographic plate. These radiations would pass through thin sheets of substances, which are opaque to light. He also discovered that these radiations were characteristic of uranium and are independent of temperature and the physical and chemical state of the specimen. The emission of invisible energetic radiation from uranium and other substances is called radioactivity. Those elements that emit the energetic radiation are called radioactive elements.

18.3. Alpha, Beta and Gamma Radiation

Soon after the discovery of radioactivity, scientist found that radioactive elements emit three types of radiations. They are named as α-, β-, and γ - radiation. These radiations can be separated by a simple experiment.

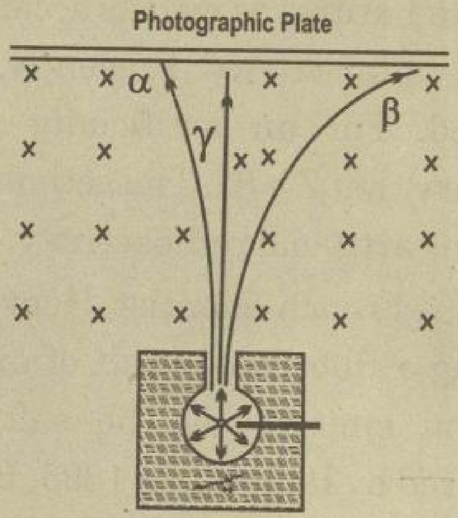


Fig. (18.2) Emission of α-, β-, γ- radiations from radioactive substance

A small quantity of a radioactive substance such as radium is so placed in a cavity in a block of lead that the radiation from radium can come out of the mouth of the cavity, Fig.(18.2). A photographic plate is placed at some distance above the lead block so that radiations from radium fall upon it. This apparatus is placed in vacuum tight chamber, which is evacuated by a powerful pump. This chamber is then placed between the poles of a strong magnet so that the magnetic field is perpendicular to the plane of the paper and is directed inward. Under the action of the magnetic field, two of the three types of radiations are deflected. Three separate images are formed on the photographic plate. This shows that the radiations coming out of radium are of three types. One of these are those radiations which bend towards the left and give rise to a black spot on the plate close to the central one. The direction and the extent of deflection show that these radiations consist of positively charged particles, which are quite massive. Further experiments show that these particles are nuclei of helium. These ***radiations are known as alpha (α) particles.***

The second type of radiation are those which bend towards right and form a black spot on the plates at a comparatively larger distance from the central spot. This indicates that these radiations consist of negatively charged particles. Later experiments have shown that these particles are actually electrons. These ***radiations are known as beta (β) particles.***

The third type of radiations gives rise to the black spot at the centre. The fact that these radiations move straight in the magnetic field without any deflection show that magnetic field has no effect upon them. This indicates that these rays are neither positively charged particles nor negatively charged particles. Further experiments showed that their nature is similar

18.4. Properties of Radioactive Rays

α-Rays or -Particles:

Experiments show that -rays consists of such particles which are nuclei of helium. These rays posses the following properties.

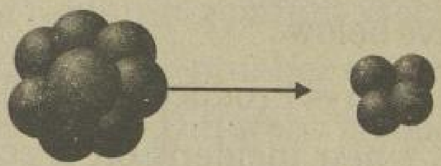


Fig. 18.3. Emission of α-particle from nucleus

i. The mass of each -particle is nearly four times the mass of hydrogen nucleus.
ii. The charge on each -particle is positive and is twice the charge on a proton.
iii. The ionization capability of -rays is very large.
iv. Penetrating power of these rays is very small. In air, they penetrate only a few centimeters.
v. α-rays produce fluorescence in certain substances.
vi. When these particles are allowed to pass through a thin metal foil such as gold foil, some of them are scattered through large angles.
vii. α-rays can induce artificial radioactivity in certain substances.
viii. These rays produce burns and sores on human body

β-rays or -particles

These rays consist of fast moving electrons. They possess the following properties

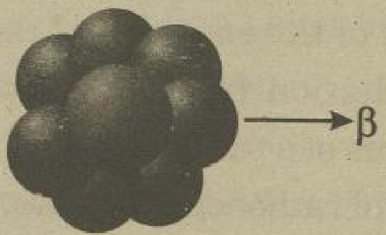


Fig. 18.4. Emission of β-particle from nucleus

i. The kinetic energy of β-rays is less than that of α-rays.
ii. These rays affect the photographic plate
iii. These rays produce fluorescence easily, especially, in barium platinocynide
iv. The ionization power of β-rays is very small
v. The velocity of β-particles range from $2.710^{7}ms^{-1}$ to $9.010^{7}ms^{-1}$

γ-rays

These rays are not affected by magnetic field. It is, therefore, concluded that γ-rays do not possess any kind of charge. Experiments show that they are electromagnetic radiations similar to X-rays. Their wavelength is very short ($\gamma \cong 10^{-10}$m) and the energy is very high. Some of their other properties are give below

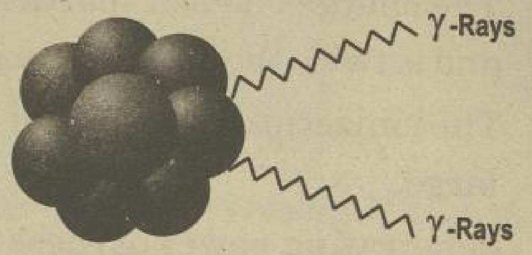


Fig. 18.5. Emission of γ-rays from nucleus

i. γ-rays produce feeble fluore-scence when incident on a screen coated with barium platinocynide.
ii. They eject electrons when incident on metals.
iii. The speed of these rays is equal to that of light.
iv. Like x-rays, these rays also get absorbed in various materials.
v. Penetrating power of -rays is very large. It is about hundred times larger than that of beta rays.

18.5. Half Life of Radioactive Elements

We have already learnt that radioactive elements continuously emit radiations. As a result, they transform into new elements. The element emitting radiations is known as parent element. The element formed as a result of the emission of radiation is called daughter element. The emission of radiation from a radioactive substance is a spontaneous process. The nucleus of a radioactive substance can emit radiation any time. If we have an atom of radioactive substance, we cannot guess that when this atom is going to decay. It is quite possible that it may decay the next moment. It is also possible that thousand years may pass and it may not decay. Hence the age of an element ca n not be estimated by considering the decay of a single atom. On the other hand, if we have a very large number of atoms, say10^5 atoms, then we find out the time when half of them will decay into daughter elements.

The time interval in which half of the atoms in any given sample decay into daughter elements is known as the half life of the parent element.

Thus if we start with a sample of 100,000 atoms of a radioactive element with a half life of T, then after a lapse of time T, 50,000 atoms of the element will decay into daughter element and the number of remaining parent atoms will be 50,000. After a lapse of another period of time T, the number of atoms of the parent element will reduce to 25,000 and so on. Different radioactive materials have different half-lives which ranges from 10^{10} years to fraction of a second.

Example 18.1.

Radium has a half-life of 1600 years. How much of 40 grams of radium will be left after 3200 years?

Solution:

Number of half-lives of radium in 3200 years = 3200/1600 = 2 half-lives

Amount of radium after first half-life = ½ × 40 gm = 20 gm

Amount of radium after second half-life = ½ × 20 gm = 10 gm

So, out of40gm, 10 gram of radium will be left after 3200 years.

18.6. Isotopes

Presently, it is well known that the atoms of some elements have the same number of protons Z but they have different number of neutrons N. In other words, the atoms of the same elements have different mass number A and have different masses. ***Species of the same element that have the same atomic number Z but have different mass number A are called isotopes of that element.***

Isotopes of an element have exactly the same chemical properties.

Hydrogen has three isotopes: protium $_1H^1$; deuterium; $_1H^2$ and tritium $_1H^3$. Protium has one proton and no neutron; deutrium has one proton and one neutron. Tritium has one electron and two neutrons.

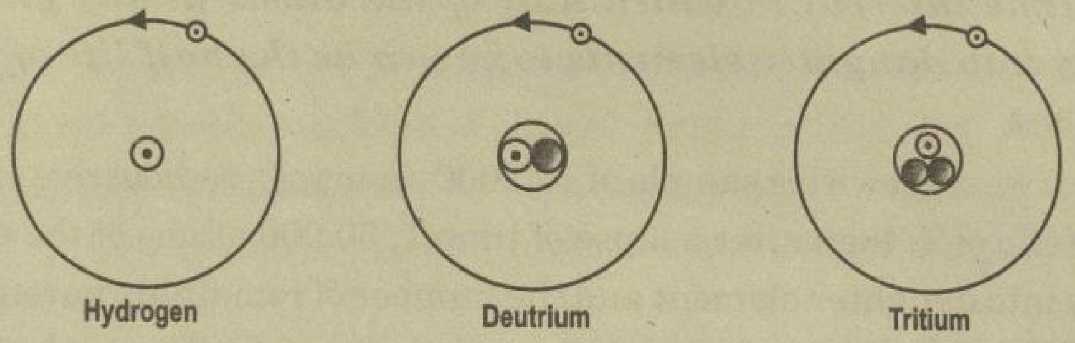


Fig.(18.6) Isotopes of hydrogen

It is found that almost all the elements have more than one isotope. For example, Tin has 10, iron has 4, oxygen has 3, uranium has 3 and carbon has 2 isotopes.

Radioisotope

Some isotopes occurring in nature are stable but some are unstable. They decay and are radioactive. Such isotopes are known as radioisotopes. Many of them are naturally occurring. Radioisotopes can also be produced artificially by bombarding subatomic particles into some elements. Examples of artificially produced radioactive isotopes are sodium (${}_{11}Na^{24}$), carbon (${}_{6}C^{14}$), phosphorus (${}_{15}P^{32}$), cobalt (${}_{27}Co^{62}$) and (${}_{53}I^{131}$).

Uses of Radioisotopes

Though all the isotopes of an element behave in the same manner chemically, but one distinct advantage of a radioisotope is that its location can be easily identified by the radiation it emits. This property has made radioisotopes very useful in medicine, agriculture, industry and archaeology. In the following, we will describe the use of radioisotopes in these sectors.

♦ Medicine

Radioisotopes have helped in understanding the basic working of many of the internal organs and vital metabolic processes. They have also helped in the diagnosis of many complicated diseases. Radioisotopes have also played a vital role in determining the effectivity and absorption of medicine in various parts of the body.

Radio phosphorous-32 and iodine-131 as tracer to trace out the path of an element in the body of plant, animal or human body. The position of the radioisotope in the body can be detected from outside the body by the radiation it emits. This allows some diagnosis about internal organs to be made without surgery. Iodine-131 is used for the study of thyroid glands. Phosphorous-32 is used to locate precisely the position of tumor in the brain Radio sodium has been extremely useful in tracing the blood circulation in the body.

Certain types of cancers also respond to treatment by radiation emitted by radioisotopes. Certain type of cancerous cells absorbs radioisotope radiation preferentially. This helps in locating the cancerous portions of the body precisely, which can then be treated by radiation from radioisotopes. The role of radioisotopes in medicine is continuously growing.

Agriculture

Pest resisting and higher yield varieties of seeds are very important in agriculture. Such varieties of different seeds have been developed after mutation through radiation.

Radiation is also used to kill bacteria and preserve fruit, vegetable and other foodstuff.

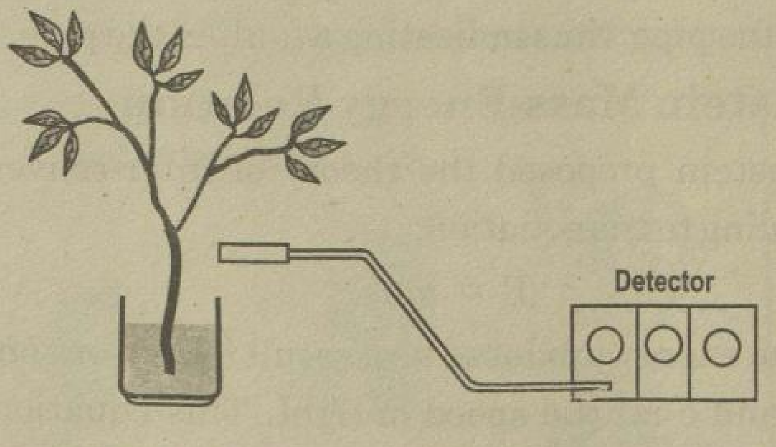


Fig.18.7. Detection of radiation in a plant.

Radioisotopes are used to determine the optimum amount of fertilizers and other nutrients intake by plants. A minute amount of radioisotope of the chemical whose absorption by the plant is to be determined is mixed with the ordinary chemical. The whole is then dissolved in water. A detector placed near the various parts of the plant can identify the location of absorbed chemical. The count rate will determine how much of the chemical has been absorbed by the various parts of the plant. In this way the exact location of the absorbed chemical, as well as the quantity of chemical absorbed can be precisely determined. This and similar methods have helped to cut down the amount of water, pesticides, fertilizers and other nutrients to be given to various plants.

Industry

Estimate of wear and tear in machine tools is extremely important in various industrial processes, especially in moving parts like bearings. If the radioisotope is impregnated into the bearing, the bearing filing, obtained as a result of wear and tear, are washed away by lubricating oil. An examination of the radioactivity of the bearings filling containing oil will reveal the wear of the bearing.

Co-60 emits high-energy gamma rays. It can be used to detect cracks in welded joints.

Radioisotopes can also be used to detect leakage in pipes. This is done by introducing small quantities of radioisotopes into the fluid in the pipe. A radiation detector can be used to check whether the radioisotope is leaking anywhere in the pipe, thus indicating a fault in the pipe.

18.7 Einstein Mass-Energy Relation

In 1905, Einstein proposed the theory of inter-conversion of matter and energy according to the equation:

$$E = mc^2$$

where E is the energy produced as a result of conversion of m mass of matter into energy and c is the speed of light. This equation is known as *mass-energy relation.* Nuclear fission will be discussed in the next section. Only the help of mass-energy relation can explain the enormous amount of energy that is released in the fission process.

Example 18.2. How much energy will be generated when 1 kg of uranium is completely converted to energy?

Solution:

Mass of matter = m = 1 kg

Speed of light = c = $3 \times 10^8\ ms^{-1}$

According to Einstein mass-energy relation

$$E = mc^2$$

Substitute the given values in this equation:

$$E = 1\,kg \times (3 \times 10^8\ ms^{-1})^2$$

$$= 9 \times 10^{16}\ \text{joule}$$

This is a huge amount of energy. It is equivalent to the energy produced by the burning of one million kilogram of coal.

18.8 Nuclear Fission

Otto Hahn and Fritz Strassmann in the year 1938 bombarded the uranium nucleus with slow neutrons. Neutrons, being uncharged particles, were expected to enter into the nucleus and form a heavier isotope of uranium. However they observed that instead of formation of a heavier nucleus, the nucleus itself broke into two fragments with the emission of an enormous amount of energy.

$${}_{92}U^{235} + {}_{0}n^{1} \longrightarrow (\text{Unstable})\ {}_{92}U^{236} \longrightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\,{}_{0}n^{1} + \text{energy}$$

where, ${}_{56}Ba^{141}$ and ${}_{36}Kr^{92}$ represent the barium and krypton nuclei.

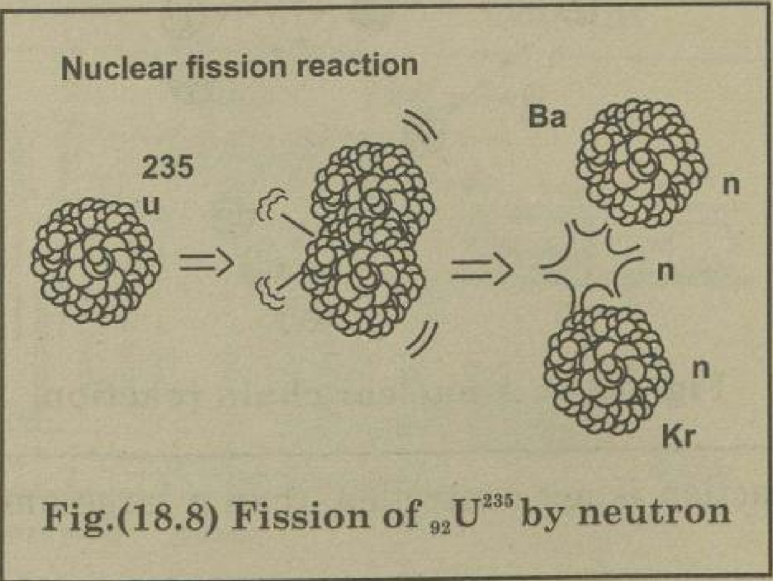


Fig.(18.8) Fission of ${}_{92}U^{235}$ by neutron

The splitting of a nucleus into fragments with the emission of energy when bombarded by a neutron is called nuclear fission. In a fission process, the nucleus breaks, in general, into two parts. Two to three neutrons are emitted in each fission process. The energy released in a fission process is due to the fact that, when a nucleus splits into fragments, the total mass of the fragments is less than that of the nucleus and the neutron, which has caused the nuclear fission. This mass difference, according to Einstein mass-energy relation appears as energy.

Fission Chain Reaction

As discussed above, in a fission process each nucleus emits about two to three neutrons. These neutrons may collide with the other uranium nuclei and cause fission in them. The nuclei, which undergo a fission reaction, will emit neutrons. These neutrons will produce further fission on other nuclei. If this process continues, more and more neutrons are produced. A large amount of energy is released. This is called a nuclear chain reaction. Fig. (18.9) illustrates a nuclear chain reaction.

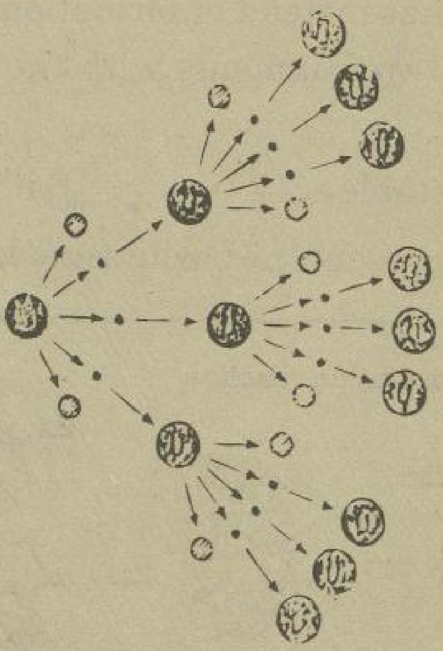


Fig. (18.9). A nuclear chain reaction.

If the chain reaction is not controlled, then a large amount of energy is released in the form of heat and kinetic energy of the fission fragments. The release of a huge amount of energy in a very short time is, in fact, the explosion of an atomic bomb.

Controlled Fission Chain Reaction

As discussed above a fission chain reaction releases a large amount of energy. If the energy is not controlled, it becomes an atomic bomb. Fortunately, it is possible to control the reaction. In fission chain reaction, each neutron, released in each fission, causes further fission. It is possible to control the neutrons in such a way that only one neutron in each fission is allowed to cause fission. All the remaining neutrons are either taken away from the uranium mass or so moderated that they cannot cause further fission. In this way a steady and a continuous reaction is maintained and energy is available at a steady rate. This energy can be used for useful purposes. A system used to obtain a controlled amount of energy from nuclear fission is called a nuclear reactor. It is also worth noting that a certain minimum mass of uranium is required so as to maintain in it a continuous fission reaction. This mass of uranium is called ***critical mass.***

Nuclear Reactors

A nuclear reactor is a system that generates nuclear energy by the process of nuclear energy. It has the following parts:

i. **Fuel**
ii. **Moderator**
iii. **Neutron absorber**
iv. **Coolant**

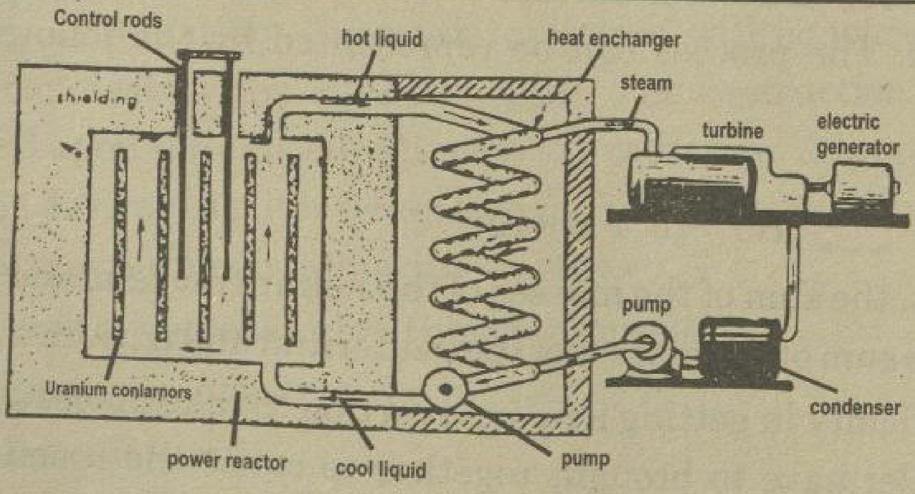

Control rods
hot liquid
heat enchanger
steam
shielding
turbine
electric generator
pump
Uranium conlarnors
condenser
power reactor
cool liquid
pump

Fig. (18.10) Nuclear reactor

Fuel: Uranium $_{92}U^{235}$ is used as the fuel. It is in the form of rods.

Moderator: Slow neutrons cause fission. It is, therefore, necessary to slow down the fast neutron produced in the fission. Graphite or heavy water is used to moderate the speed of fast neutrons.

Neutron Absorber: To control the rate of nuclear fission by neutrons, cadmium and boron rods are used to absorb neutron. These rods can be moved up and down between the fuel rods. The number of neutrons reaching the fuel rods can be controlled.

Coolant: The fuel rods, the neutron absorbers and the moderator together are called the core of the reactor. Coolant is required to cool down the core. The coolant absorbs heat energy from the core and transfers it to a boiler where the superheated steam is produced. The steam runs a turbine for generation of electricity. Such reactors are in use in Karachi and Chashma. The plant at Karachi is known as Karachi Nuclear Plant (Kanup) and produces 137 megawatt of electricity.

18.9. Nuclear Fusion

The nuclear process in which two light nuclei, ($A < 30$), fuse together to form a single nuclide is called nuclear fusion. The sum of the masses of the combining nuclei is more than the product nuclide. As a consequence of the decrease in mass, energy is released in the fusion process. In fusion process, the energy released per unit mass of matter is far more than in fission process. As an example, when deuterium and tritium nuclei are brought together, they form a helium nucleus and release a large amount of energy and a neutron. The process can be represented by the following nuclear reaction;

$$_1H^2 + {}_1H^3 \longrightarrow {}_2He^4 + {}_0n^1 + \text{Energy}$$

In this process, the sum of the masses of the helium nucleus and the neutron is less than the sum of the masses of the deuterium and tritium nuclei.

The major difficulty in getting a fusion reaction to take place is that the two positively nuclei have to brought together to cause the reaction. For this purpose the two particles must have a huge amount of kinetic energy to overcome the electrostatic repulsion as the two nuclei approach each other. The only way to supply such energy to the two nuclei, so that they overcome the repulsive force and fuse together, is by heating. A temperature of more than one million degree celcius is required for this purpose.

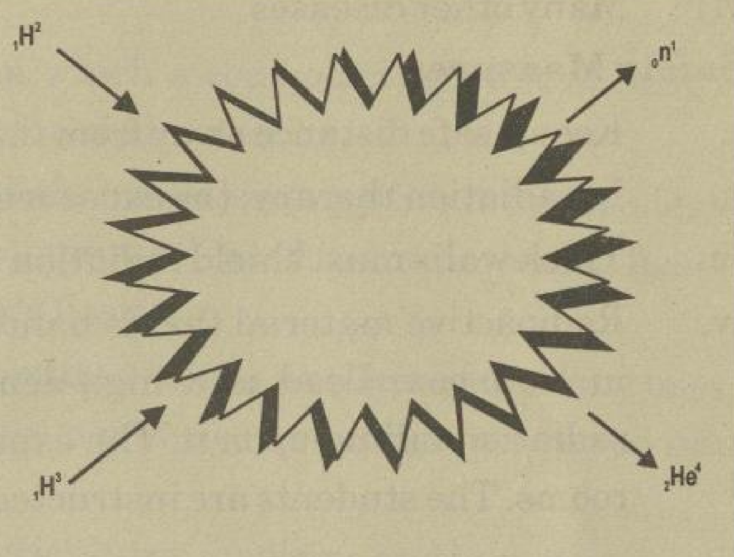


Fig. (18.11) Nuclear fusion

No fusion reaction has far been possible in which the heat obtained from the fusion process can be utilized for peaceful purposes. This is due to the fact that such an extremely high temperature has not yet produced steadily in any laboratory on the earth. Such a temperature can exist in the interior of the sun and other stars. In a hydrogen bomb, high temperature is attained by using fission process. The later starts the fusion reaction.

18.10. Hazards of Nuclear Radiation

Nuclear radiation can be very dangerous to the human body. They can damage our body cells. Excessive radiation may cause cancer or incurable radiation sickness to a human being.

The destruction of the cell is caused by the ionizing properties of the radiation. The amount of ionization produced depends upon the intensity and energy of radiation. Energetic radiation will penetrate deep into the body and can destroy the vital body cells. The destruction of the body cells also depend upon the exposure time to the radiation. A large number of body cells will be destroyed if it is irradiated for a longer time. A person, if strongly irradiated, may suffer the following diseases.

1. Anemia (a decrease in red blood corpuscle)
ii. Leukemia or blood cancer
iii. Malignant tumor
iv. Cataracts (Opacity of lens of the eyes)

v. Many other diseases

Safety Measures

i. Keep a safe distance away from the radiation emitting sources.

ii. In radiation therapy, the exposure time for radiation be minimized.

iii. Thick walls must shield radiation from a reactor.

iv. Radioactive material that is handled in a laboratory must be covered in lead box. Lead is a high-density material and therefore stops radiation falling upon it. The experiments are performed in separate rooms. The students are instructed to handle the apparatus carefully.

SUMMARY

The nucleus of an atom is composed of neutrons and protons. The neutrons and protons in a nucleus are both termed as nucleons.

The radiations emitted from a radioactive substance are α, β and γ-rays.

The α-rays are highly energetic particles. Each particle consists of two protons and two neutrons. In fact, α-particle is a helium nucleus.

The β-rays are fast moving electrons. They carry negative charge.

γ-rays are very energetic electromagnetic waves. They are emitted when α or β-emission leaves the nucleus in an excited state.

The time during which half the atoms of a radioactive substance decay is called the half-life of that radioactive substance.

The isotopes of elements have the same atomic number but different mass numbers. Some isotopes are radioactive and they are called radioisotopes.

When mass is converted into energy it releases energy equal to mc^2. The same amount of energy is required to convert it into mass. This is called Einstein's mass-energy relation.

The splitting of nuclei of a substance into two or more fragments, with the emission of energy, is called nuclear fission. Two to three neutrons are also emitted in each fission. If these neutrons cause further fusion in other nuclei and this process continues then it is called chain reaction.

A nuclear reactor is an assembly in which a controlled amount of heat is obtained by controlling a nuclear fission chain reaction.

In the process of nuclear fusion, two light nuclei join together to form a single nucleus and energy is released. The energy released in the process of fusion is larger than released in the process of fission.

Nuclear energy and the radiations emitted from a nucleus have many uses. For example, heat energy obtained from a nuclear reactor is converted into electricity.

The emitted radiations are used in agriculture, medicine and industry.

Excessive exposure to radiation is dangerous to health. Safety measures are taken to protect from radiations.

OBJECTIVE QUESTIONS

1. **Encircle the correct answers from the possible given answers**

i. α-particle has:

(a) two neutron (b) two protons

(c) two neutron and two protons (d) one helium atom

ii. β- particle is the following particle emitted by a nucleus:

(a) proton (b) neutron

(c) electron (d) deuteron

iii. When α-particle passes through a gas, it produces:

(a) oxidation (b) ionization

(c) evaporation (d) fission

iv. Electric and magnetic fields have no effect on:

(a) α-particle (b) β-particle

(c) gamma rays (d) quark

v. Which of the following is more penetrating

(a) α-rays (b) β-rays (c) γ-rays (d) X-rays

2. Encircle T for true and F for false

i. The nucleus of ${}_{92}U^{238}$ has equal number of protons and neutrons. T/F

ii. The emission of α-particles from radium is an example of nuclear fission. T/F

ii. β-particle is a nucleus of hydrogen. T/F

iii. γ-rays carry positive charge. T/F

iv. The mass of helium nucleus is equal to the sum of the masses of two protons and two neutrons. T/F

3. Fill in the blanks

i. The size of the atom is ___m. whereas the size of of its _____ 10^{-14} m

ii. Every α-particle carries ______ charge.

iii. The velocity of α-rays are of the order of __________

iv. β-rays are fast moving _______

v. _______ rays are not deflected by electric and magnetic fields

vi. In --------- reaction, two light nuclei are combined to form a heavy nucleus.

vii. In_______ reaction, A _______ nucleus splits into fragments

viii. An element of ${}_{86}Rn^{222}$ which contains x protons and y neutrons, where x = ------- and y = --------

ix. Nucleus of _______ is called alpha particle.

x. The time in which half of the atoms of an element decay is called____

SHORT ANSWER QUESTIONS

1. Which particles are contained in a nucleus? Describe their characteristics.
2. What do mass number and charge number mean? Give examples.
3. What is meant by radioactivity? Is it dependent on the physical state of matter?

4. What are radioisotopes? Give examples.
5. What is meant by half-life of a radioactive element?
6. What is a nuclear reactor?
7. Explain briefly Einstein's mass-energy relation.

COMPREHENSIVE QUESTIONS

1. What is radioactivity? What are α, β and γ-rays? Describe their properties.
2. What are radioisotopes? Discuss the uses of these isotopes in medicine, agriculture and industry?
3. Discuss in detail nuclear fission.
4. Discuss in detail nuclear fusion.
5. What is a nuclear reactor. Discuss its working and uses.
6. How radiation from radioactive substances can harm us? How can we protect against these radiations?

NUMERICAL PROBLEMS

1. The half-life of radium is 1600 years. How much of 120 gram of radium will be left after 6400 years? **[7.5 g]**
2. Half-life of uranium is 4.47×10^9 years. In how much time only 10 gram will be left out of 40 gram. **[2 half lives = 8.94×10^9 years]**
3. Find the mass of the body from which 2.70×10^{15} J of energy is obtained when the mass is annihilated. **[30g]**

Chapter 19

ELECTRONICS

In this chapter you will study

- Electronics and its importance
- Analogue and digital electronics
- Semiconductors, n-type and p-type materials
- p-n junction diode
- Forward bias and reverse bias to junction diode
- Diode as a rectifier
- Transistor and its applications
- Logic gates
- Applications of logic gates

19.1 Introduction

Electronics is a branch of physics that deals with the development of electron emitting devices and their utilization. Usually, it deals with controlling electron flow in diodes, transistors and semiconductor devices designed for various purposes. Electronics have influenced our daily life. Radio, television, stereo hi-fi sound system, motion pictures and videocassette recorder etc. provide a lot of entertainment and information.

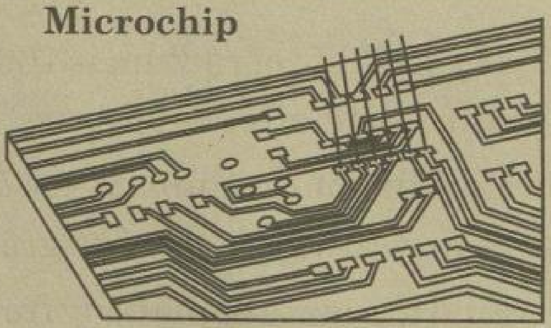


Fig.(19.1) A microchip equal to the size of thumb nail has about one thousand electronic devices

Similarly, automatic washing machines, microwave ovens, robots, telephone systems and pocket calculators have made jobs simpler and convenient.

These satellites are to scan earth's natural resources and to collect data on weather and climate.

The biggest achievement of electronics is computer, which has taken the whole world in its grip. By using the facility of Internet, provided by computers, we can contact any institution of the world and get the required information. Now-a-days computers are being used even for shopping purposes. By E-mail, we can immediately communicate anywhere in the world. Computer is the pivot of the whole information technology. Computer's influence is increasing very rapidly in our life.

19.2. Analogue and Digital Electronics.

Electronics can be classified into two main branches: analogue electronics and digital electronics. In practical applications, a combination of both the branches is often utilized.

Those quantities whose values vary continuously or remain constant are known as analogue quantities. For example, the temperature of the air in the atmosphere is continuously changing during day and night. If we draw the graph of the air temperature versus time at which it is measured, it will be of the form shown in Fig.(19.2). The graph shows that temperature varies with time. Temperature is an analogue quantity. The branch of electronics consisting of such circuits, which processes analogue quantities, is called analogue electronics.

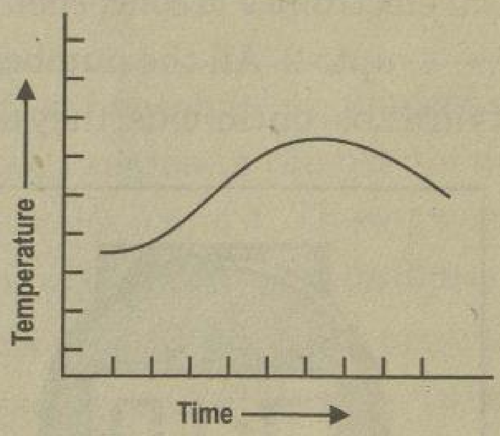


Fig. (19.2) Room temperature varies continuously with time

The public address sound system shown in Fig.(19.3) is another example of analogue electronic system. In this system, the microphone converts the sound of the speaker into electrical signals. The sound signal of the speaker is a variable or an analogue signal. The electrical signals sent out by the

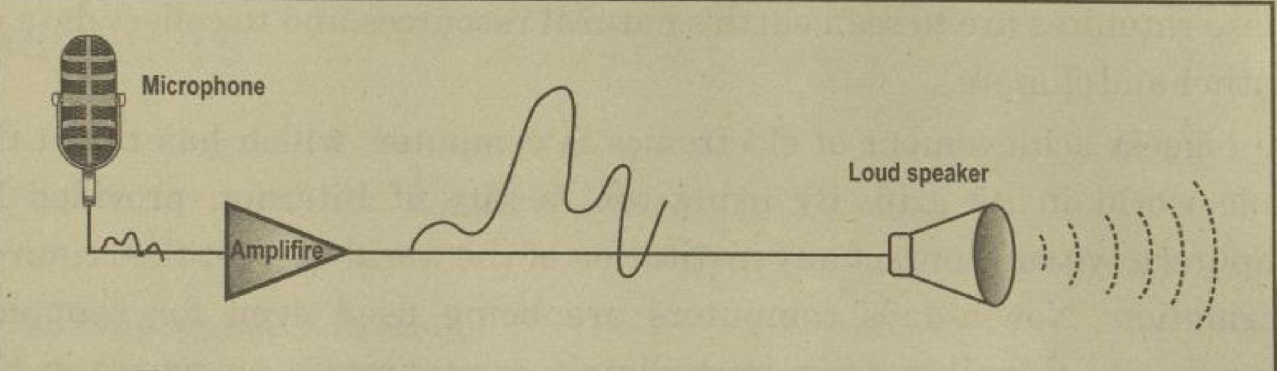


Fig. (19.3). A public address sound system (analogue)

microphone are also analogue signals. The output of the microphone is fed into an amplifier, which is also an analogue instrument. The amplifier amplifies its input without changing its shape and operates a loudspeaker. In this way, a loud sound is produced out of the speaker. Besides the above mentioned public address system, radio, TV, tape recorder and analogue watch, are other electronic devices, which make use of analogue electronics.

Digital electronics is concerned with digital data. Digit means the figures 0, 1, ... upto 9. All the numbers are made from these digits. Note that the digits are not continuous; they are discrete.

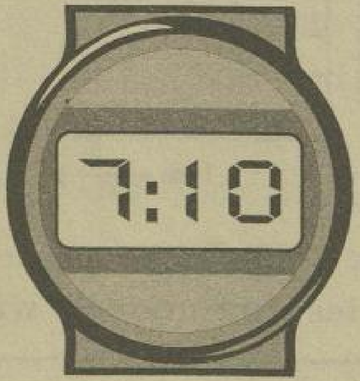


Fig.19.4 . Digital watch.

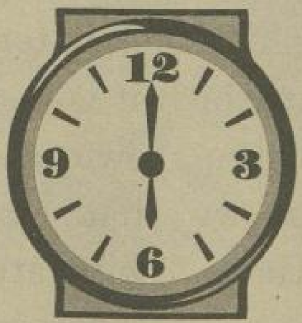


Fig.19.5. Analogue watch

The branch of electronics, which provides the data in the form of a maximum and minimum voltage signals, is known as digital electronics. Fig. (19.6) shows a digital data. In this type of data, the changes are not continuous. In fact, one part of the data is quite distinct from the other part of the data.

Modern telephone system, radar system, naval and other communication systems of military importance is using digital electronics. The operation of industrial machines, medical equipment and many other household appliances make use of digital electronics technology. The main reason of the use of digital technology is that it makes use of only two digits 0 and 1. These two digits provide a full fledge binary system which makes it easy to provide data.

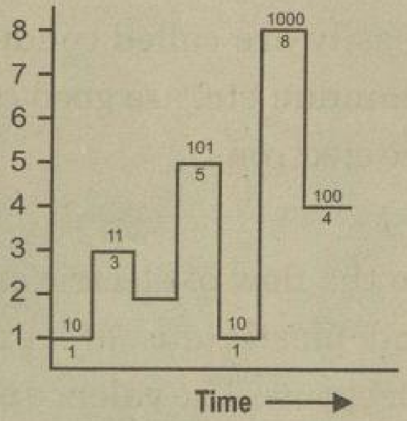


Fig.(19.6) (a) Analogue voltage signal

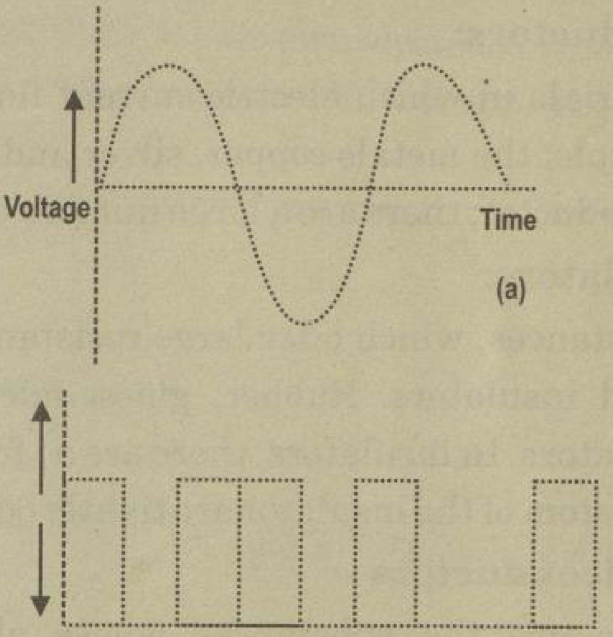


Fig. (9.7) Digital voltage signals

The things that we perceive by our senses in our daily life are usually analogue quantities, which cannot be processed by digital circuits. To resolve this difficulty, a circuit has to be designed which converts the analogue signal into digital one. This circuit is known as analogue to digital converter, i.e. ADC. When we get analogue signal in the form of digital, then we can process it with digital circuit, the output of which is also in digital form. The digital output is converted into analogue form by a circuit known as digital to analogue converter (DAC). As the output of DAC is an analogue signal, we can readily sense it. The electronic systems used at present consist of both analogue and digital type circuits.

19.3. Semiconductors

On the basis of the electrical properties, materials can be classified into three classes: conductors; insulators and semiconductors.

Conductors:

Materials in which electric current flows easily are called conductors. For example, the metals copper, silver and aluminium etc. are good conductors. In conductor, there are a large number of free electrons.

Insulators:

Substances, which offer large resistance to the flow of electric current, are called insulators. Rubber, glass, mica and plastic etc. are examples of insulators. In insulators, there are no free electrons. The valence electrons in each atom of the insulator are tightly bound to their respective atoms.

Semiconductors

These are the substances whose ability to conduct current at room temperature lies in between conductor and insulator. Germanium and silicon are two main semiconductors. Let us see how these substances possess the property of semiconductor.

Germanium and silicon belong to the fourth group of the periodic table of elements. So, every atom of these materials has four valence electrons. In an atomic state, a valence electron is under the influence of Coulomb's force of a positively charged ion core. The valence electrons revolve round the ion core. Model of the isolated silicon atom is given in Fig.(19.8) Germanium atom has very similar electronic structure.

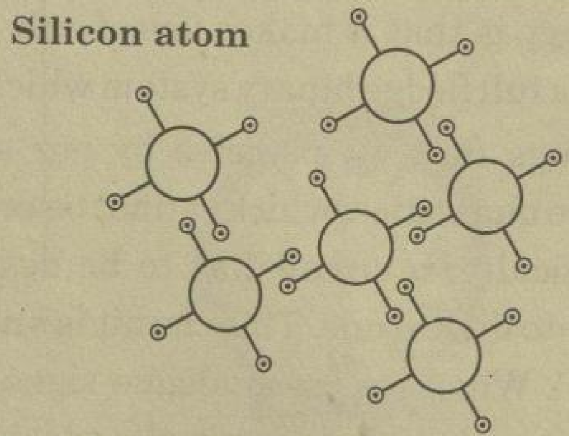


Fig.(19.8) Model of Si atom

In solid state and at temperature below room temperature, pure germanium and silicon crystals are insulators. At room temperature, these materials are semiconductors. In crystalline state, the four valence electrons of each atom are bound to its neighbouring atoms in a very special manner, Fig. (19.9b). In this figure, you see that instead of four, there are eight electrons present in orbit around the core. Four of them are its own electrons whereas the four neighbouring atoms provide one electron each. Now it appears as if there are eight electrons around the core.

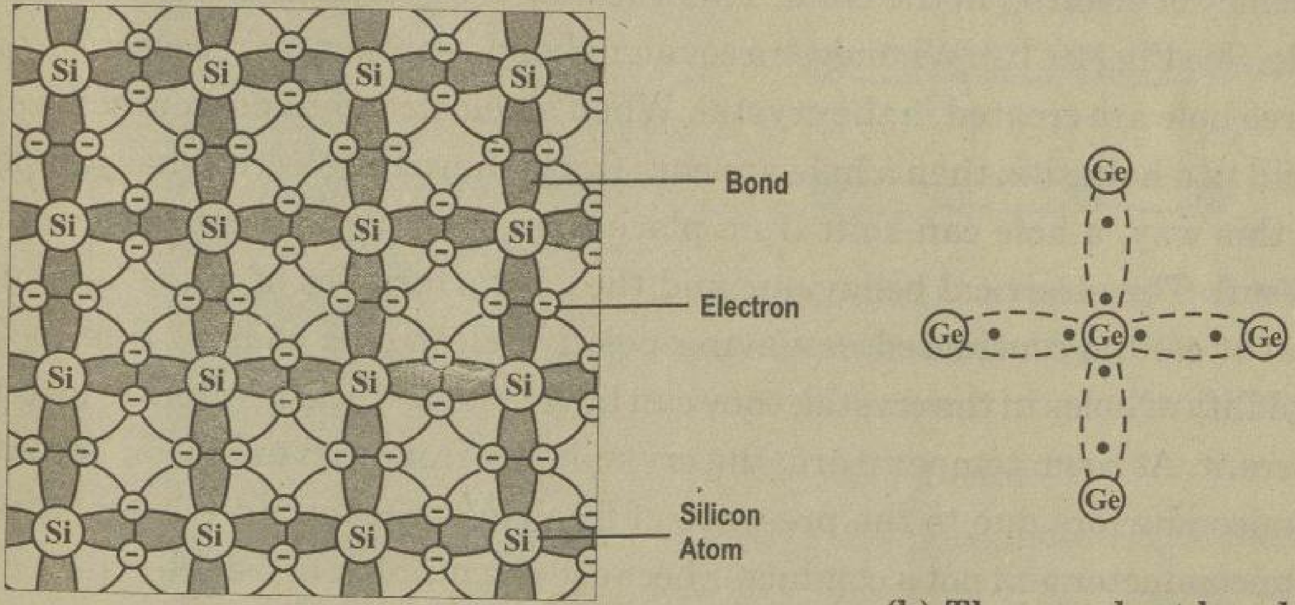


Fig. (19.9) (a) Silicon atoms in a Si ctystal

(b) The covalent bond between atoms

We know that when the number of electrons in an orbit is eight, then it is a very stable configuration. The electrons do not want to change this configuration. In this way, by their mutual sharing, every valence electron is firmly bound to the core of its mother atom. This type of binding of atoms is called covalent bonding.

In the crystals of germanium and of silicon, all the valence electrons are firmly bound in

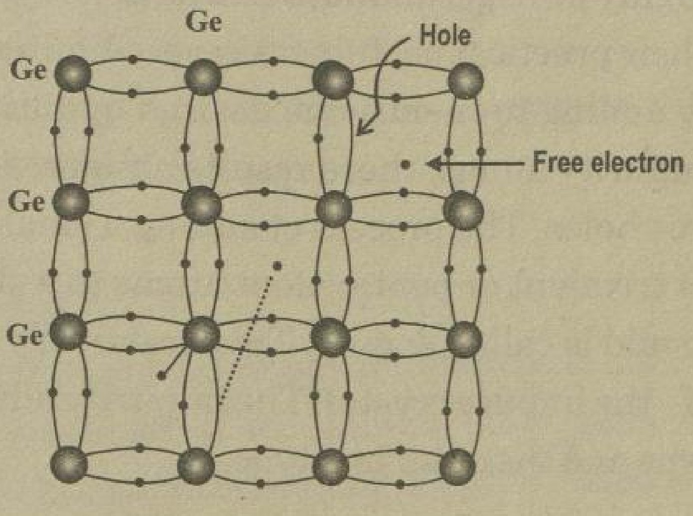


Fig.(19.10). Thermal agitation breaks some bonds , liberates electrons and creates holes orbits by covalent bonding. So, there are no free electrons available for electric current. This type of state exists at low temperature and the pure crystals are insulators. At room temperature or above it, some electrons attain so much energy that they move with enough speed to break away from the covalent bond. In this way, some electrons become free to move anywhere in the crystal. The crystal becomes semiconductor.

Wherever an electron gets free from the bond, there appears a deficiency or a vacancy of electron in the bond. This vacancy of electron in an orbit is called hole. See Fig.(19.10). Whenever a covalent bond is broken, a free electron and a free hole are created in the crystal. When an electron jumps from some site to fill in a hole-site, then a hole appears from where the electron has jumped. In this way, a hole can shift from place to another equivalent place in the crystal. The electrical behaviour and the characteristics of a hole are such that it can be considered as having positive electronic charge. Due to the mobility of holes in the crystal, they can be considered contributors to electric current. At room temperature, the crystal of germanium or silicon becomes semiconductors due to the presence of free electrons and free holes. It is a semiconductor and not a conductor because the number of free electrons and free holes is far less than those contained in a conductor.

19.4. Doping

Highly pure germanium and silicon crystals are very feeble semiconductors. Their practical usefulness is very limited. However, they can be made useful by adding to them some desired quantity of impurity atoms. Depending on impurity atoms, there results an increase in the number of free electrons or free holes. The process of adding a small specified quantity of impurity such as trivalent or pentavalent atoms to a single crystal while it is drawn from a mould is called doping. This drastically increases the electrical conductivity of the impure crystal. The impurity added crystals are of two types: one is n-type and the other is p-type.

19.5. n-type Semiconductors

When a silicon crystal is doped with a pentavalent element such as arsenic (As), then four out of five valence electrons of the impurity atom form four covalent bonds with four neighbouring silicon atoms. The fifth valence electron is however, free to move about. This makes the doped silicon crystal a better conductor. We call this material an n-type semiconductor because the fifth valence electron of each pentavalent atom is available to form an electric current.

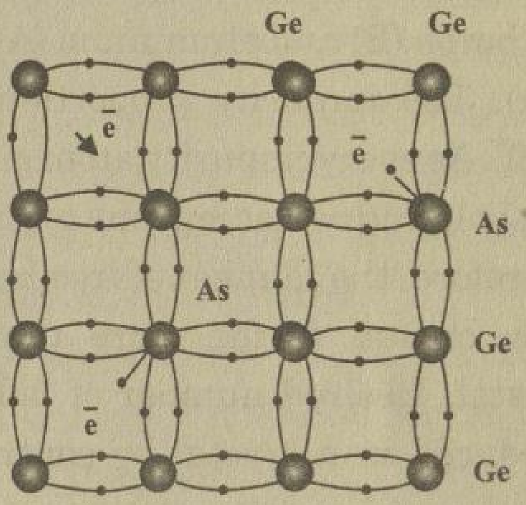


Fig.(19.11) n-type crystal with arsenic as an impurity

Germanium can also be made as an n-type semiconductor.

Besides arsenic, other pentavalent elements are phosphorous (P), bismuth (Bi) and antimony (Sb). The impurity ratio is about $1:10^8$, that is, for 10^8 atoms of silicon or germanium there is one atom of the impurity. As every impurity atom donates one free electron to the crystal, the number of free electrons in n-type semiconductor is far more than a pure crystal. A desired concentration of free electrons can be produced in the crystal by controlling the concentration of impurity atoms in the doping process.

Current in n-type material is mainly due to the free electrons. These electrons are, therefore, called majority carriers.

19.6. p-type Semiconductors

If a silicon crystal is doped with a trivalent element such as indium (In), then all the three available valence electrons of an indium atom form three covalent bonds with three neighbouring silicon atoms. A space called a hole is, therefore, left in the silicon crystal due to the shortage of an electron. This hole behaves like a positive charge, and can move from place to place in the crystal. Such a material is called a p-type material. It is worth noting that the holes flow in the direction opposite to electrons.

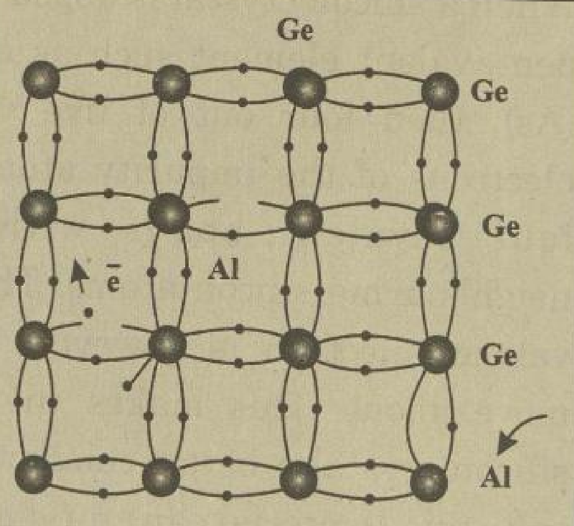


Fig.(19.12) p-type crystal with Aluminium as an impurity

Besides indium, other trivalent elements are boron (B) and aluminium (Al), gallium (Ga). The impurity proportion is about 1:10^8. As every impurity atom gives rise to one hole and can accept one more electron, therefore, the number of free holes in a p-type crystal is far more than a pure crystal. Desired number of holes can be produced in a crystal by controlling the number of impurity atoms in the doping process.

Current in a p-type material is mainly due to free holes. A hole behaves like an electron with a positive charge. In a p-type holes are often called the majority carriers.

19.7. p-n Junction

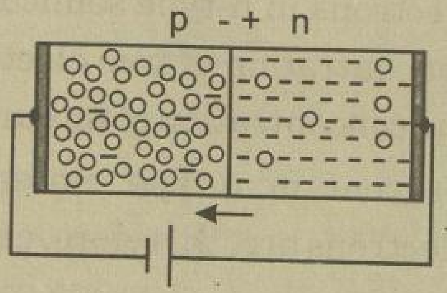


Fig. (19.13) p-n junction

If a crystal of silicon or germanium is doped in such a way that its one part becomes n-type and the other p-type, then p-n junction would be formed in between. On one side of this junction, there would be a region of n-type having free electrons as majority charge carriers. On the other side of the junction, there would be a region of p-type having holes as majority charge carriers as shown in Fig.(19.13). In this figure, the short black lines show electrons while small circles represent holes.

Just after the formation of p-n junction, some of the electrons of n-type region, due to their free random motion cross the junction and enter into the p-type region where the holes are in abundance. When an electron reaches the site of a hole, it fills up the vacant site and becomes the part of the orbit of impurity atom having that hole. The impurity atom, with its three valence electrons was a neutral atom, but the electron fills the hole present in its orbit, then the number of electrons in its orbit becomes four. In this way this atom is converted into a negatively charged ion. Note that in a crystal, every atom has a fixed seat, so the negative ion does not move from its place. In this way, as more and more electrons enter into the p-region from the n-region, **a layer of immobile negative ions is formed in the p-region**.

Now let us observe the changes, which take place in the n-region as the free electrons leave this region. This region contains pentavalent impurity atoms, which have five valence electrons in their last orbit. Four of these electrons are bound by covalent bonds while the fifth one is free. As this electron leaves its parent atom and enters into the p-region, the number of electrons in this particular impurity atom gets short by one. Thereby, the impurity atom is converted into an immobile positive ion, In this way as more and more electrons enter from n -region into p-region, **a layer of positive ions, adjacent to the junction is formed in the n-region.**

These layers of positive and negative ions formed just across the junction in the n- and p-regions are shown in Fig.(19.14). These layers of positive and negative ions create a potential difference across the sides of the junction. Therefore, a positive potential appears at the n-type junction and a negative potential appears at the p-type junction. This potential difference tends to stop the motion of electrons from n-region to p-region. As the electrons continue to cross the junction from n- to p -region, the layer of positive and negative ions across the junction becomes wider. This also increases the potential difference created by these layers till it reaches to such a value that it completely stops the entry of the electrons from n- to p-region. As this potential difference does not allow the electrons to

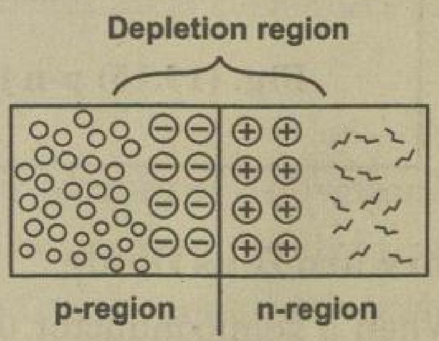


Fig.(19.14) Formation of depletion layer

cross the junction from n- to p-region, so it is known as potential barrier, Fig.(19.14). In case of silicon its value is 0.7 volt and in case of germanium its value is 0.3 volt.

The region of the layers of positive and negative ions across the junction does not contain free electrons or holes. So, it is known as depletion layer. See Fig.(19.14)

19.8. p-n Junction Diode

A p-n junction diode is an electronic device fabricated from a p-type and an n-type semiconductor. The junction is fixed on a brass base to which the leads are attached(Fig:19.15).

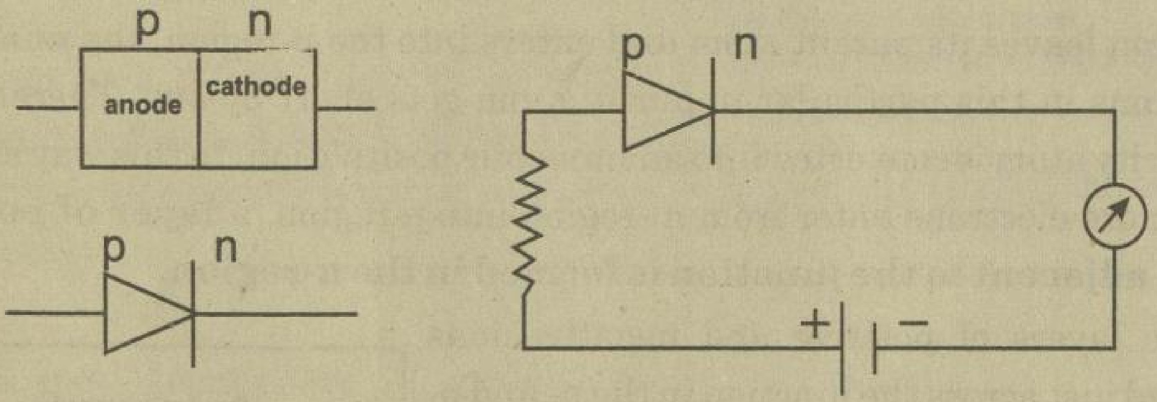


Fig. (19.15) p-n junction, Its symbol and use in a circuit

Forward Bias Diode

When a semiconductor diode is connected to a direct current (D.C) power supply (battery) as shown in Fig.(19.16), the p-type material will be at positive potential and the n-type material will be at negative potential. The positive holes will now drift across the junction from the p-type to the n-type material while free electrons will move from the n-type to the p-type material. The movement of these charges occurs because the positive

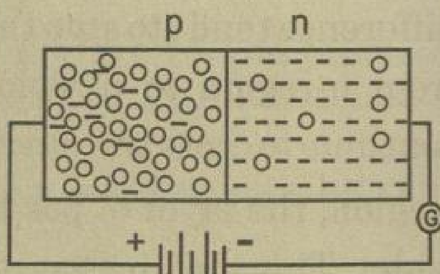


Fig. (19.16)Forward biased p-n junction

terminal of the power supply repels holes in p-type material towards the junction, while the negative terminal also repels the electrons in n-type material towards the junction. Thus an electric current can easily pass through the p-n junction. The diode has a very low electrical resistance and is said to be in a condition of forward bias.

Reverse Bias Diode

If the semiconductor diode is now connected to the D.C. power supply as shown in Fig.(19.17), the hole in the p-type material and the electrons in the n-type material will be attracted by the negative and positive terminals of the power supply and will, therefore, move away from the junction.

The flow of charge across the junction will, therefore, be zero. The region around the junction, in fact, loses its charge and becomes an insulator. Under these conditions, very little electrical current can pass through the p-n junction. The diode has a very high electrical resistance and is said to be in the reverse biased.

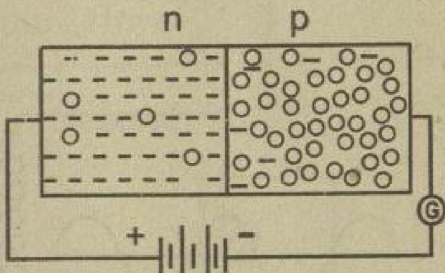


Fig. (19.17)Reversed biased p-n junction

Diode as Rectifier

A junction diode always allows current to pass through it in one direction. A rectifier is a device that converts an A.C. to a D.C. The process itself is known as ***rectification.*** Fig.(19.18a) illustrates rectification by using a junction diode. The input voltage V_i is an alternating voltage, which is to be rectified. During the positive half cycle of V_i, the p-type of the diode is positive and the n-type is negative. The diode is in the mode of forward bias. Current flows easily through the diode. A potential difference V_o appears across the load resistance R.

During the negative half cycle of V_i, the p-type of the diode is negative and the n-type is positive. The diode is in the state of reverse bias. Current does not pass through the diode. The output voltage is $V_o = 0$

Hence, we see that the current through a diode passes only during the

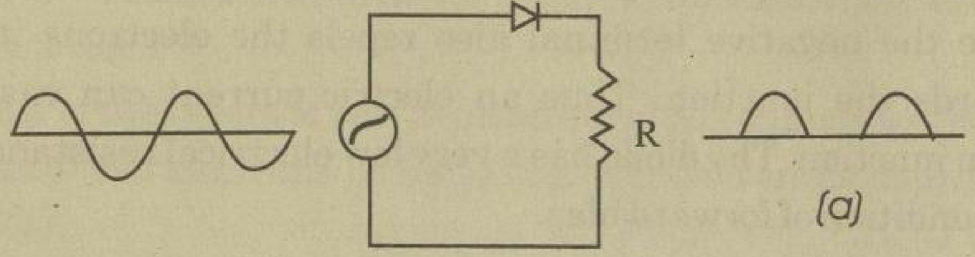


Fig. (19.18a) Half-wave rectification: the negative part of each A.C. is prevented from passing.

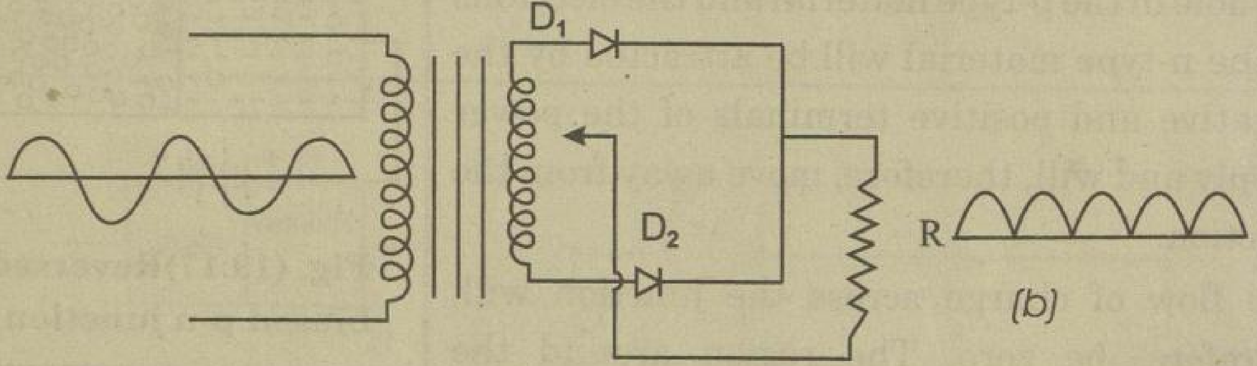


Fig. (19.18b) Full wave rectification: the negative part of each A.C. is reversed

positive half of the A.C. cycle and rectification is achieved. This is called half-wave rectification.

For better performance, full-wave rectification is achieved by using two diodes and a centre tapped transformer as shown in Fig.(19.18b)

19.9. Transistor

In 1948, three scientists Shockley, Bratain and Bardeen invented a tiny, three terminal semiconductor device called transistor. This device brought a revolution in the field of electronic devices. Transistors are now being used in radio and television sets, audio and videocassette recorders, voltage stabilizers, telephone sets, computers and numerous other devices.

Construction

A transistor is basically a semiconductor, which consists of a thin central layer of one type of semiconductor material sandwiched between two relatively thick pieces of the other type. There are two types of transistors: n-p-n and p-n-p. See Fig.(19.19). The n-p-n transistor has a thin piece of p-type material sandwiched between two pieces of n-type. The p-n-p transistor consists of a piece of n-type in between two pieces of p-type. The central part is known as the base (b). The pieces on either side are called the emitter (e) and the collector (c). In circuit diagrams, the n-p-n and the p-n-p transistors are represented by the symbols given in Fig.(19.19). The arrow on the symbol gives the direction in which conventional current would flow.

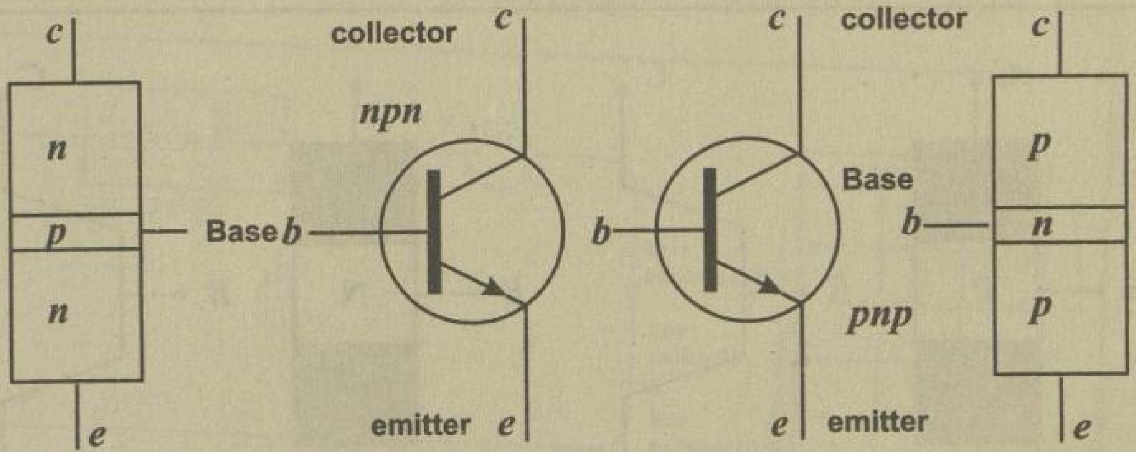


Fig. (19.19) (a) n-p-n transistor and its symbol(b) p-n-p transistor and its symbol

Operation of Transistor

A transistor consists of two p-n junctions. One is the emitter-base (e-b) junction and the second is the collector-base (c-b) junction. For normal transistor operation e-b junction is always forward biased. The c-b junction is reversed biased. As the b-e junction is forward biased, a current begins to flow across this junction by injecting a stream of electrons from emitter to base. Current I_e starts flowing in the emitter circuit. The resistance Re controls this current. As the base region is very thin, all the electrons injected into the base region are attracted towards the collector due to its large positive potential, Fig.(19.20). Due to small base potential, only a few electrons enter in base circuit, Current I_b flows in base and current I_c in collector circuit. Since the emitter current is divided into base and collector currents, therefore,

$$I_e = I_b + I_c$$

Thus there are two current paths through a transistor. One is the base-emitter path (input) and the other is the collector-base path (output). The importance of a transistor is due to the fact that if the base-emitter potential or base current I_b is changed by a small amount then the collector current I_c changes by large amount.

Transistor as an Amplifier

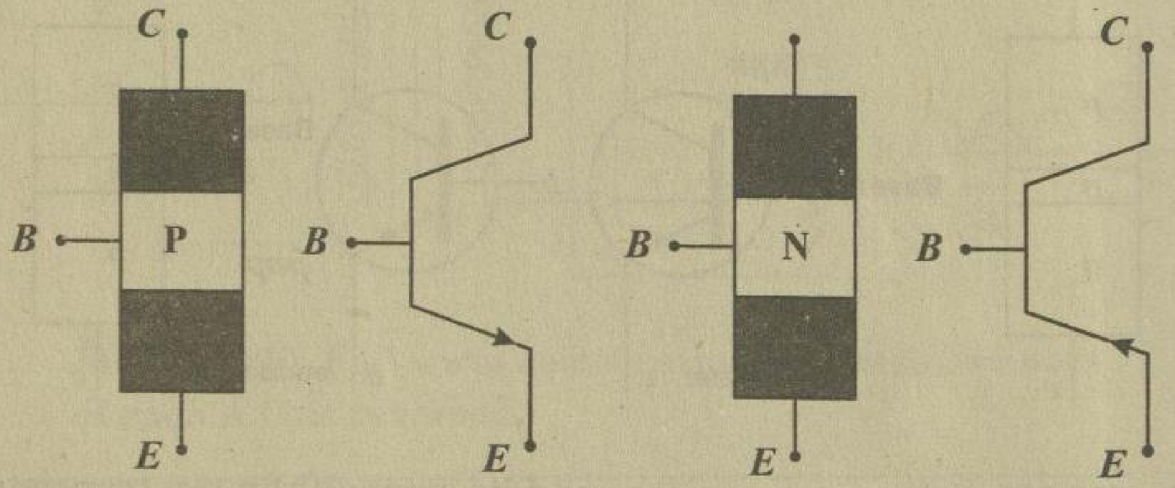


Fig.(19.20) Operation of n-p-n transistor

In a transistor, the base current I_b plays a vital role in the collector current. A small change in the base current produces a large change in the collector current. Due to this characteristic, a transistor is used as an amplifier in various electronic circuits. A block diagram of an amplifier is shown in Fig. (19.21)

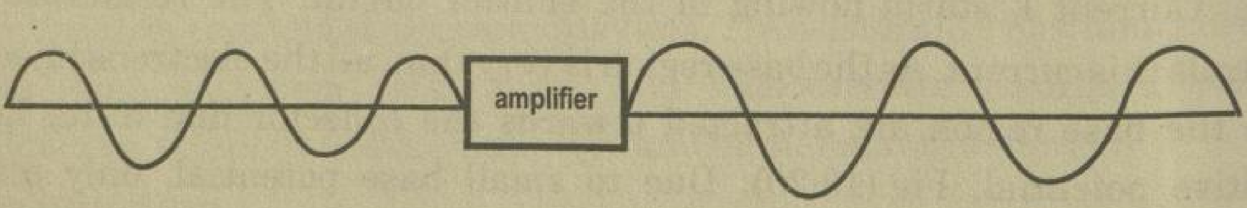
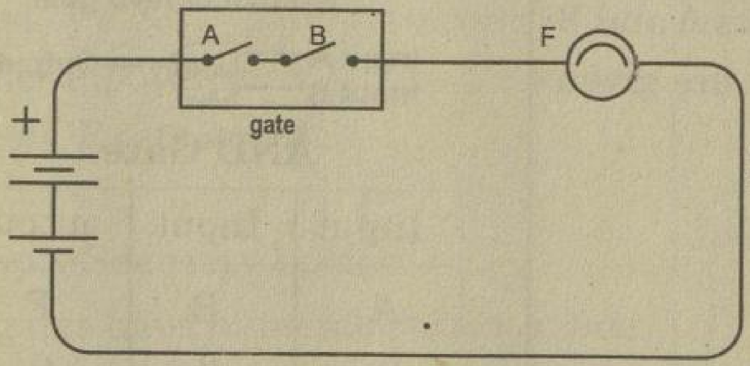


Fig.19.21. Block diagram of an amplifier

19.10. Electronic Logic Gates

Precious articles, cash and important documents etc. are kept in safes. The door of a safe is opened and closed by a certain order of a set of switches. A systematic ordered system is called a logic gate. If the buttons of switches are pressed in right order, the door of the safe will open. However, if the buttons are pressed in wrong order, the alarm begins to ring.

The gates controlling safes are very complicated. Fig.(19.22) illustrates a simple electric gate comprising of only two switches. If both the switches are closed, the bulb stays ON. If either switch is open, the bulb stays OFF.



	switches		bult
	A	B	F
both switches OFF	0	0	0
one switch ON	0	1	0
	1	0	0
both switches ON	1	1	1

Fig. (19.22) Simple logic gate

To express the working of a logic gate, a logic table of the gate is prepared. This is called the truth table. Truth table gives the outcome of every possible switching. A truth table makes logical use of the binary numbers 0 and 1.

- Logic 0 stands for OFF
- Logic 1 stands for ON

Electronic gates do not use ordinary 'lever' switches. They use transistor switches instead. They have one or more input lines, and one output line.

A Line is ON if there is a positive voltage on it.

A Line is Off if there is a negative voltage on it [0 volt].

Types of Gates

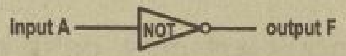
There are several types of logic gates. The symbols of the main gates and their truth tables are given below. Electric power is supplied to the gates. The power supply is not shown in the figures.

Logic 0 is for Off and logic 1 is for ON.

NOT Gate

The output of the gate is ON if the input is Zero. This type of gate is called inverter: it changes OFF to ON and ON to OFF. Its symbol and truth table are given in the adjacent figure.

Symbol of NOT gate



NOT Gate

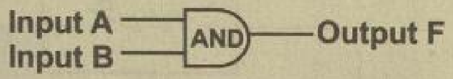
Input A	Output F
0	1
1	o

Fig. (19.23a) NOT gate & its Truth Table

AND Gate

The output is ON if both inputs A and B are On. Its symbol and truth are given in the adjacent figure.

Symbol of AND gate



AND Gate

Input	Input	output
A	B	F
0	0	0
0	1	0
1	0	0
1	1	1

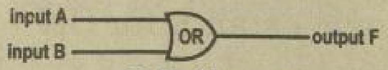
Fig. (19.23b) AND gate & its Truth Table

OR Gate

The output is ON if either input A or B is ON.

Its symbol and truth are given in the adjacent figure.

Symbol for OR gate



OR Gate

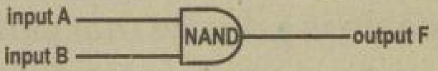
Input	Input	output
A	B	F
0	0	0
0	1	1
1	0	1
1	1	1

Fig. (19.23c) OR gate & its Truth Table

NAND Gate

NAND gate is equivalent to AND gate followed by a NOT gate. Its output is ON if input A, AND input B are NOT both ON. Its output is that of AND gate inverted.

Symbol for NAND gate



NAND Gate

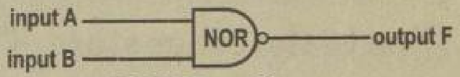
Input	Input	output
A	B	F
0	0	1
0	1	1
1	0	1
1	1	0

Fig. (19.23d) NAND gate & its Truth Table

NOR Gate

NOR gate is equivalent to OR gate followed by a NOT gate. Its output is ON if neither input A nor B is ON. Its output is that of OR gate inverted.

Symbol for NOR Gate



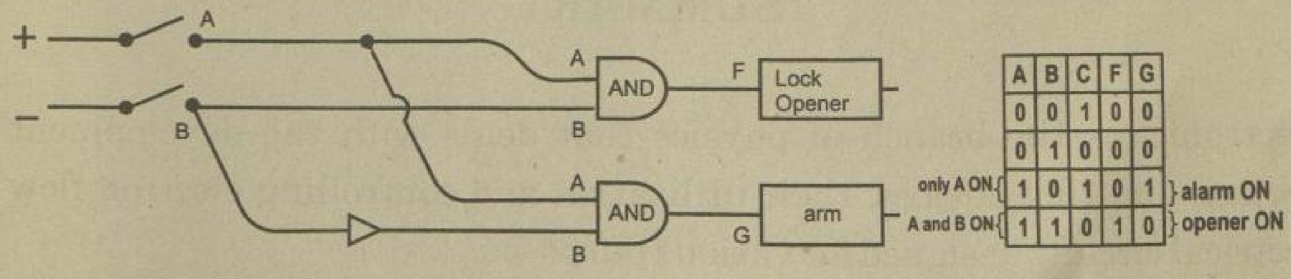
NOR Gate

Input	Input	output
A	B	F
0	0	1
0	1	0
1	0	0
1	1	0

Fig. (19.23e) NOR gate & its Truth Table

A Simple Security Lock

Logic gates have numerous applications. As an example, a simple security lock is designed here. The electric lock comprises of two switches and is installed on a shop. The shopkeeper knows that one switch is hidden, The system of logic gates that the shopkeeper decides to use together with its truth table are given in the following Fig. (19.24). The logic is that if the hidden switch is pressed first the main switch will open the door. But if the hidden switch left off, the main switch will turn on the alarm instead.



A	B	C	F	G
0	0	1	0	0
0	1	0	0	0
1	0	1	0	1
1	1	0	1	0

Fig. (19.24). Simple security lock with truth table

A Bistable

A bistable is a device that can stay in one of its two stable states for indefinite time. A bistable formed from two logic gates is shown in Fig.(19.25). Two NOR gates are connected in cross mode so that the output from one acts as one of the inputs of the other. The bistable has two stable states:

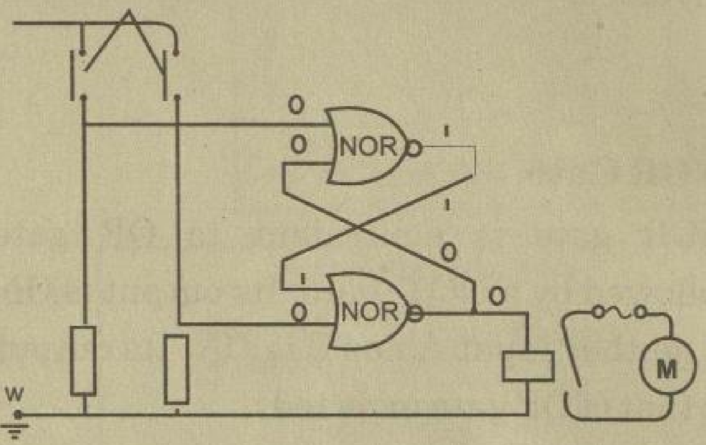


Fig (19.25) A bistable

- If both inputs are Off, either the top output is On and the bottom output is Off, as shown in the figure or vice-versa.
- If the top input is made positive [ON], the bistable flips to the other state. The top output goes Off, and the bottom output comes ON. The input signal does not have to be maintained. One short positive pulse is all that is needed to make the change. Unlike a simple gate, a bistable remembers that input has been made.

A Latch

A bistable with just one of its outputs in use is called a latch. By applying pulses to its inputs, the output can be made to go ON and Off alternately. With this kind of latch, a relay can be used to control electric motors. The ON-Off buttons of video recorders work on this kind of latch.

SUMMARY

Electronics is the branch of physics that deals with the development of electron emitting devices, their utilization and controlling electron flow in electrical circuits designed for various purposes.

Electronics has two main branches: analogue electronics and digital electronics.

Analogue electronics deals with variable quantities. Digital electronics processes the data being provided in the form of digits. The data is binary.

A pure semiconductor material doped with a pentavalent element is called n-type substance.

A pure semiconductor material doped with a trivalent element is called a p-type substance.

The junction formed by separating n-type material from p-type material is called p-n junction. Current can flow through p-n junction in only one direction. So, p-n junction diodes are used to convert A.C. to D.C., i.e. used as rectifiers.

A transistor is a semiconductor that consists of a thin central layer of one type of semiconductor material sandwiched between two relatively thick pieces of the other type. Transistors are tiny, light and durable electronic components. They work on small voltage and consume very little power. They are used in TV,CD's, electric switches, logic gates and almost every electronic instrument.

Presently, multipurpose transistor circuits are printed. Integrated circuits [IC's] are available in the form of microchips.

Basic types of logic gates are NOT, AND, OR, NAND and NOR. Logic gates have many applications. Logic gates are of special use in computers.

OBJECTIVE QUESTIONS

1. **Fill in blanks**

i. Silicon crystal doped with pentavalent element is called______

ii. In case of a forward bias the resistance of the diode is almost_____

iii. In reverse bias of a p-n junction diode, the electrons and holes are----------------from the junction

iv. Holes are charge carriers in ______ material.

v. p-n junction is used as a ___________

2. **Encircle the correct answer from the possible given answers**

i. A substance through which current passes easily is

(a) insulator (b) conductor (c)semiconductor

ii. By increasing the temperature, the resistance of a semiconductor

(a) becomes smaller (b) becomes higher

(c) remains constant

iii. Silicon becomes p-type by doping with ________ element

(a) divalent (b) trivalent (c) tetravaent (d) pentavalent

iv. In forward bias of a p-n junction, the positive terminal of a battery is connected to

(a) p-type (b) n-type (c) p or n-type (d) none of them

v. Charge carriers in n-type material are

(a) electrons (b) holes (c) ions (d) protons

vi. The output of an OR gate will be 0, when

(a) both inputs are 0 (b) either of the inputs is 0

(c) both the inputs are 1 (d) either of the inputs is 1

vii. The output of AND gate will be 1 if

(a) both the inputs are 0 (b) either of the input is 0

(c) both the inputs are 1 (b) either of the input is 1

(viii) The inputs of a NAND gate are A and B. Its output will be 0 when

(a) $A=0, B=0$ (b) $A=1, B=0$

(c) $A=0, B=1$ (d) $A=1, B=1$

(ix) The inputs of NOR gates are A and B. Its output will be 1, if

(a) $A=0, B=0$ (b) $A=1, B=0$

(c) $A=1, B=1$ (d) $A=0, B=1$

SHORT ANSWER AND COMPREHENCIVE QUESTIONS

1. What are semiconductors? Explain p-type and n-type materials.
2. Explain how a p-n junctions acts as a diode.
3. What are transistors? How do they work?
4. Explain the action of a p-n junction diode as a half-wave rectifier.

5. What is a microchip? Describe its advantages.
6. What are logic gates? Explain with examples.
7. Construct the truth table of NAND gate.
8. Illustrate NOR gate with a diagram. Construct its truth table.

Chapter 20

INFORMATEION TECHNOLOGY

In this chapter you will study:

- What is information technology?
- Different means and methods of communicating of information
- Different methods of storing information
- Methods of handling information
- Methods of processing information
- Different devices of transmission and propagation of information.

20.1 Introduction

Present time is the era of information. Modern science and technology are very rapidly discovering and inventing new techniques, skills and knowledge. In a fraction of a second, the new discoveries and information are sent to every nook and corner of the world where they are recorded and safely stored. Some times back, telephone was the only source by means of which you could talk to your relatives across the seas. Today, there are various means of communication, for example, Fax and computer Internet. Presently, the world has become a small well informed and well connected village which is called a global village.

Information technology is the technology by means of which information can be handled, processed, transmitted and recorded by applying modern science.

20.2 Communicating Information

Communicating information instantaneously over long distances by various different methods is known as telecommunication. Telephone, radio, television and computer are a few of the contemporary devices used for telecommunication. These devices or instruments communicate or transmit information of different nature in the form of sound, written words, computer data or pictures. Information is first converted into electrical signals, radio waves or light signals. These signals or waves propagate with very high speed. Electrical signals are transmitted through conducting wires. Radio waves are propagated through air and space. Light signals are sent through optical fibers.

Telephone

When you talk over a telephone, the microphone of the telephone converts sound signals into electrical signals. Electrical signals travel through the telephone cables via the telephone exchange. The telephone receiver fixed at the other end of the line receives the electrical signals and converts them back into signals of sound.

Telephone signals are sent through a network of telephone exchanges. An exchange connects two telephones on a single call. The electrical signals travel through wires to your telephone.

In between exchanges, electrical signals can be converted to light signals, which can be transmitted through optical fibers. The signals can also be converted to radio waves and can be trans-mitted in space by means of communication satellites.

In a mobile or cellular telephone, there is installed a small transmitter as well as a receiver system. This system sends out and receives call in the form of radio waves. When we talk to the mouthpiece of the telephone then the phone converts the talk into radio waves, which are transmitted to the nearby station. This station is connected to a network of telephones. Every station is specified for the service of a small region, which is called a cell. Whenever a phone caller moves from the area of one cell to that of another cell then the signals went out by this telephone are automatically connected to the station of the new cell.

Fig. 20.1. Telephone system

The signals received by a mobile telephone are converted to sound signals by the loudspeaker installed in the earpiece of the telephone receiver. The loudspeaker emits the sound.

Fax Machine

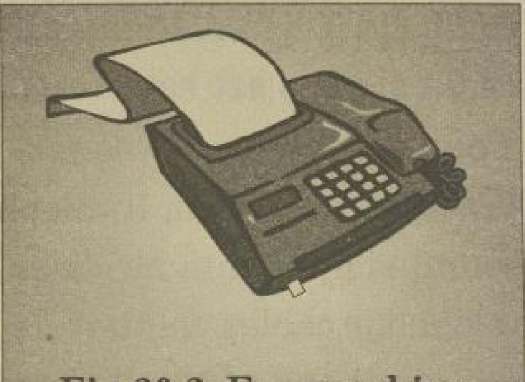


Fig.20.2. Fax machine

Fax is, in fact, abbreviation of facsimile, which means to reproduce faithfully and identical copy of a document, picture or print. Fax machine scans the document and converts its black and white parts into electrical signals. These signals travel through telephone lines and reach the receiving fax machine, which reproduces the original document

Telex Machine

Telex, teleprinter and exchange machines convert a document into electrical signals. These signals are transmitted through telephone lines to another telax machine which prints out the incoming signals and thus a copy of the original document. In telex, the original document has to be typed before it is transmitted.

Radio

Fig.(20.3) Radio receiver set

Radio transmitter is an instrument which transmits sound in the form of radio waves. Radio receiver is an instrument which receives the waves transmitted by the transmitter. In this communication system there is no need of long wires as required for telephones. The system is a wireless communication system.

In the studio of a radio station, a person talks to a microphone. The microphone converts the sound into electrical signals. The radio transmitter transmits the signals in the space in all directions in the form of radio waves. The process is shown in Fig. (20.4) by a block diagram

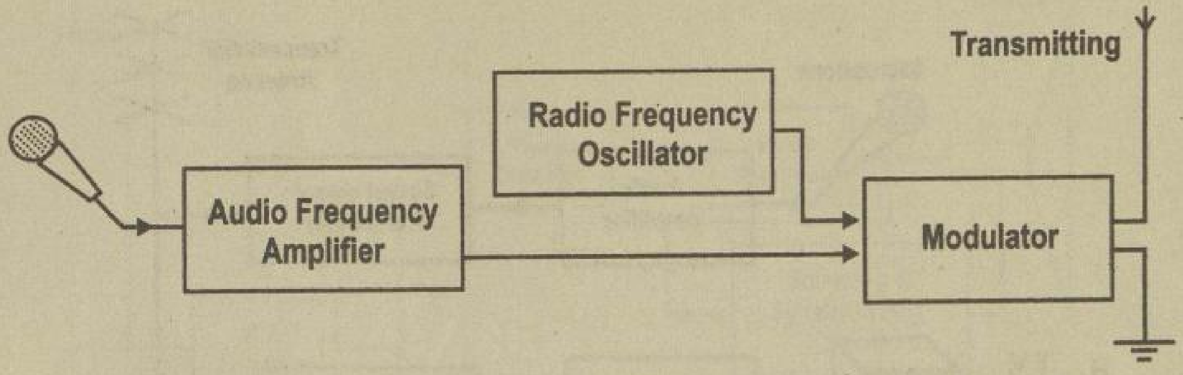

Transmitting
Radio Frequency Oscillator
Audio Frequency Amplifier
Modulator

Fig. 20.4. Block diagram of a radio transmitter

The radio receiver set in your house picks up the radio waves in space by an aerial. The aerial converts the radio waves into electrical signals and send them to the tuner in the receiver set. The radio tuner in the receiver set. The radio tuner can select the transmission of a particular radio station. The tuner sends the selected signals to an amplifier. Finally, the signals reach the loudspeaker of the radio set and are converted to loud sound signals, Fig. (20.5)

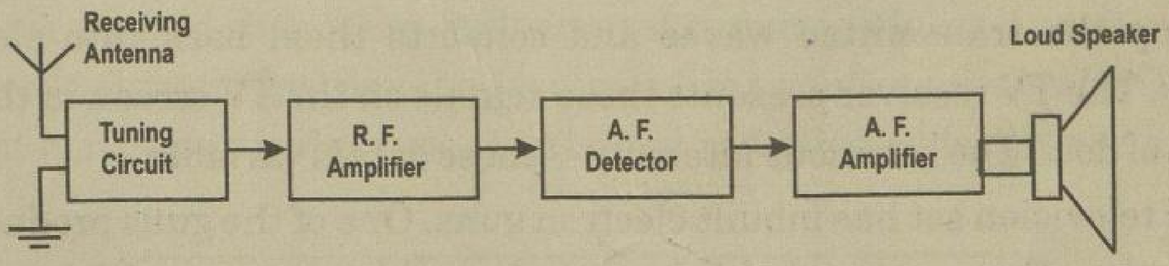

Receiving Antenna
Loud Speaker
Tuning Circuit
R. F. Amplifier
A. F. Detector
A. F. Amplifier

Fig. (20.5) Block diagram of radio receiver set

Television

Television transmits pictures and sound by means of radio waves as well as cables. Let us look into the communication starting from the TV station to your house.

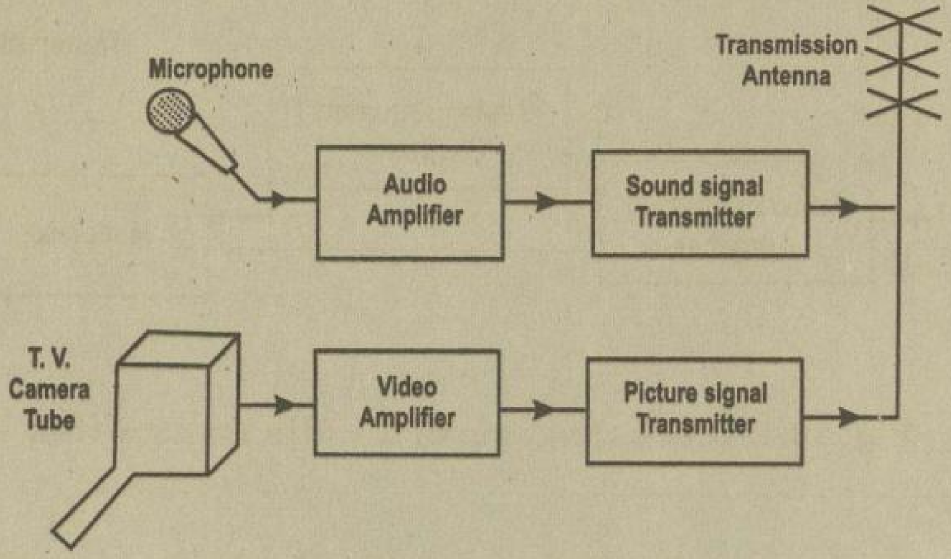

Microphone
Transmission Antenna
Audio Amplifier
Sound signal Transmitter
T.V. Camera Tube
Video Amplifier
Picture signal Transmitter

Fig:20.6 Block diagram of T.V. Transmitter

A television camera and a microphone convert moving pictures and sound into electrical signals. These signals are sent to the TV station where they are converted into radio waves.

Radio waves are transmitted by means of a TV transmitter. The TV transmitter may be stationed somewhere on the earth or it may be stationed in a satellite. The antenna or dish antenna fixed on the top of your house picks up the transmitted waves and converts them back into electrical signals. The TV receiver presents these signals on the TV screen in the form of a set of dots. The luminous intensity of these dots is variable.

A color television set has inbuilt electron guns. One of the guns produces red colour, the other green ad third one induces blue colour on the specially prepared TV screen. By the combination of the above mentioned primary colours, a picture of any desired colour can be seen on the TV screen.

In a cable television, the electrical signals are not converted into radio waves. They travel through a cable from a TV station or a ground satellite station to the TV set of a subscriber. In cable TV system, pictures and sound of high quality can be received from many different TV stations.

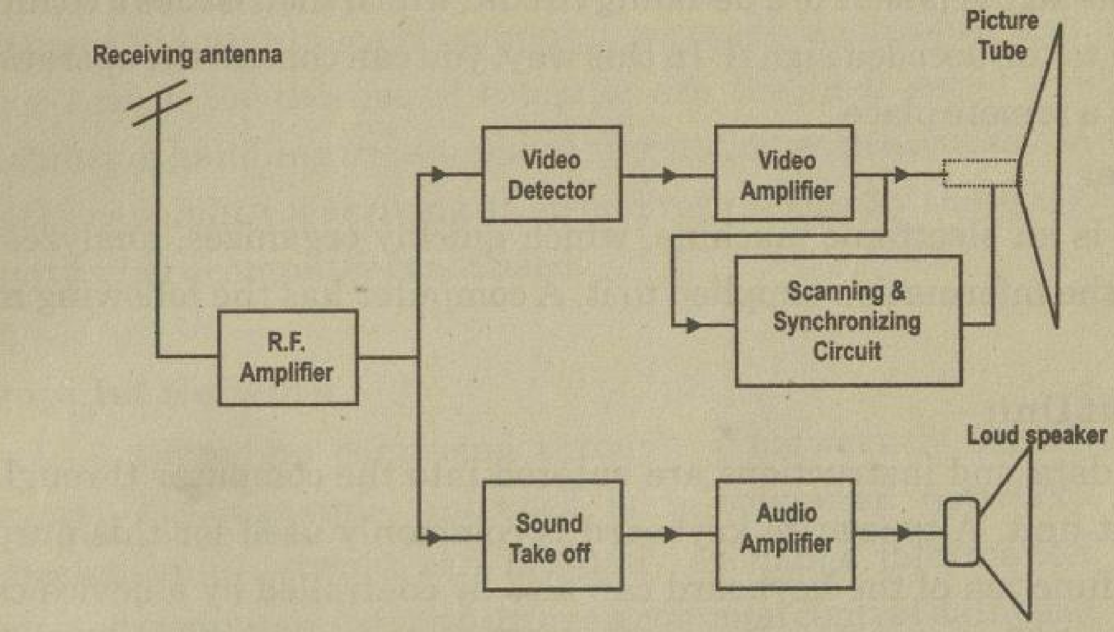

Receiving antenna
Picture Tube
Video Detector
Video Amplifier
Scanning & Synchronizing Circuit
R.F. Amplifier
Loud speaker
Sound Take off
Audio Amplifier

Fig.(20.7). Block diagram of the working of a TV set.

Remote Control System.

This is a very useful instrument and can be used to control from a distance the function of TV or other electric machine. No wire connection is needed for this type of control system. See Fig. (20.8)

Infra-red radiations are used in this system. When a button for a required purpose is pressed then an in-built control circuit produces a particular binary code signal. This signal activates a light emitting diode (LED) and makes it emit a particular type of infra-red radiation as instructed by the code.

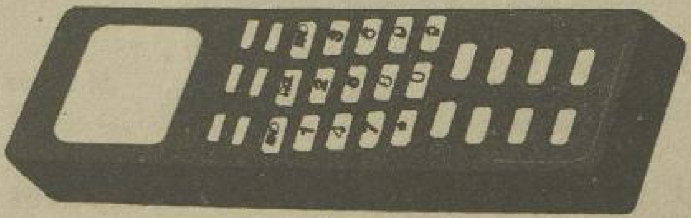


Fig. (20.8) Remote control system

When these particular radiations fall on a lens fixed on TV or electric machine then a phototransistor fixed relative to the lens identifies the signal. The signal is sent to a decoding circuit, which then issues a command according to the decoded signal. In this way, you can control the operation of a TV from a remote place.

Computer

Compute is an electronic machine, which quickly organizes, analyzes and presents the information supplied to it. A computer has the following major parts:

1. Input Unit

The data and instructions are entered into the computer through the input unit. A typewrite keyboard is commonly used for this purpose. The function of the keyboard can also by controlled by a device called 'mouse'. The input data is sent the CPU so that it may be organized and analyzed.

2) Central Processing Unit (CPU)

This unit is, in a way, the brain of the computer. It performs all the assignments. Control unit and memory units are parts of the CPU The memory unit retains safely the instructions and information for as long as we wish them to be there.

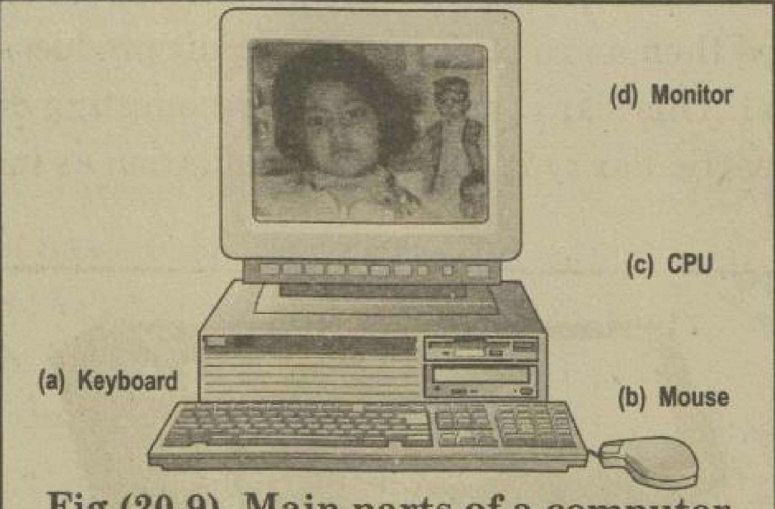


Fig.(20.9). Main parts of a computer

3) Output Unit

The outcome processes going on in the computer are finally presented by means of the output unit. The output unit is usually like a TV screen and is called the monitor. Almost all the output information can be seen on the screen of the monitor.

The use and importance of computer is rapidly increasing day by day. The major reason for the use of compute are the high speed processing, the reliability of handling the supplied information with accuracy, large memory and the capability of arriving at an end result. Hardly there is any sphere of activity where computer is not used.

Computer Network

A set of computers connected through a network is called a computer network. For example, internet is a computer network. Computers connected by a network can mutually exchange information. The interconnected computers can also utilize a common central database.

Computer networks can provide the facility of sending messages and graphics to its users. The recipients of the information can review it at leisure.

The information can also be presented on bulletin boards. Any one interested in it can use the information. Besides the above use, it is possible to hold a video conference where the participants of the conference may be thousands kilometers away from one another. The participants can see as well as talk to one another.

20.3 Storing Information

The major part of the information, about the world we live in, is in the form of print on paper. The volume of the information grew so rapidly that most of the times the information we want is difficult to search for. Besides this, it is a big problem to store the huge amount of paper. Therefore, besides paper, the tendency to find other means of recording and storing information is rapidly increasing.

Digital audiotapes, video-cassette tapes, compact discs, hard discs and optical discs etc are some of the modern methods that are used for storing information.

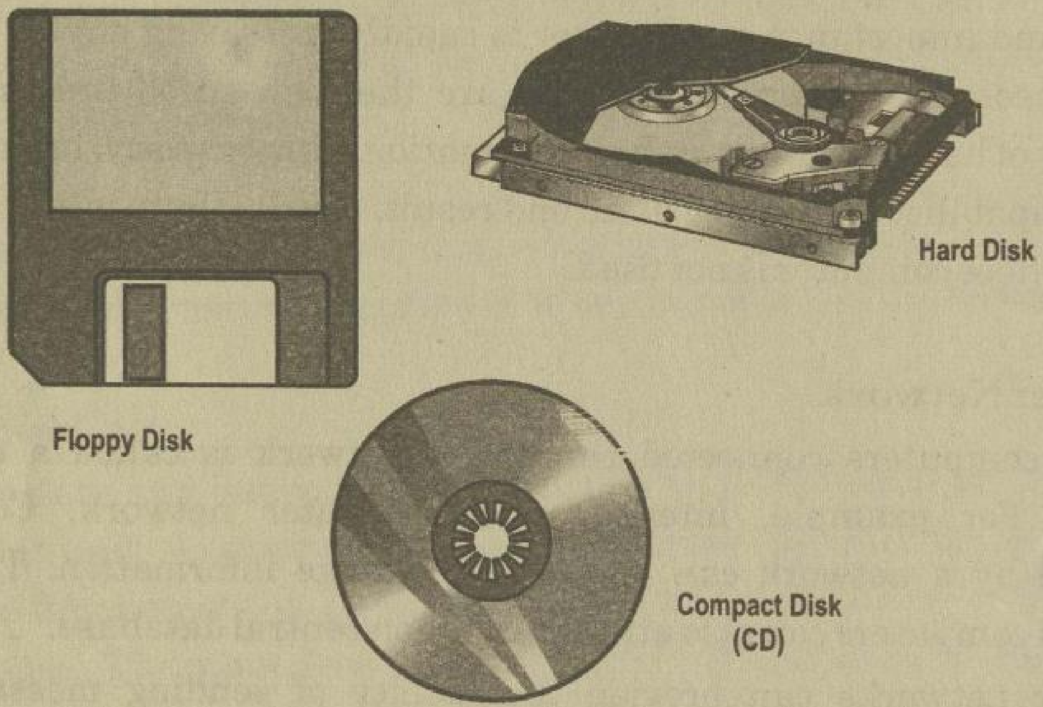


Fig. (20.10) Various devices for storing information

Magnetic material is used in preparation of audiotapes, video-cassette taps and hard disc.

In digital recording, a sound is converted into a sequence of electric pulses.

In digital audiotapes, pulses are recorded in the form of magnetic pattern. In compact discs (CD's), these pulses are recorded in the form of tiny notches. Digital recording produces high quality sound.

The information stored on CD's can be taken or read by using laser beams. A CD turns around an axis with very high speed and a laser beam shines on the disc. The level parts and the depressed notches on the CD reflect the light by different angles. A detector picks up the reflected light and converts it into electric pulses. Finally, the pulses are fed into a loudspeaker and sound is produced. A laser disc records pictures of TV or cinema just like a CD records sound.

Computer stores information and computer programs on the computer disc. Usually, a layer of magnetic material is laid up on the disc. Patterns of magnetic tracks and sectors are formatted on the magnetic layer.

Floppy Discs

Floppy discs are prepared in different sizes and of different capacities. 3″x3″ of 1.4MB floppy is very common. The magnetic diskette is safely fixed in plastic casing. A floppy disc can be inserted into as well as removed from the computer.

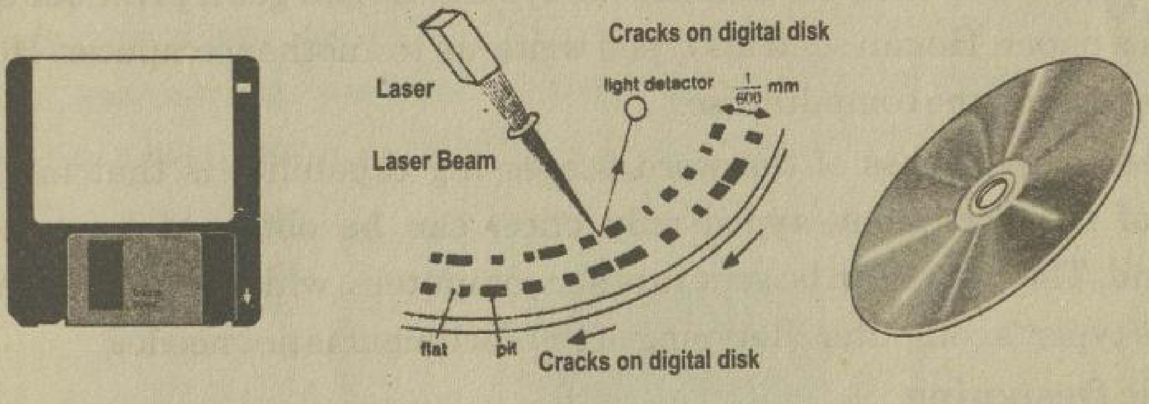


Fig. (20.11). CD's

Hard disc has much higher capacity for storing information than a floppy disc. It is fixed in a hard strong and closed box inside the computer.

Optical disc is another kind of compute disc. It is of the form of CD-Rom (compact disc-read only memory).

Information is read or extracted form the optical disc by using laser beam. Optical discs are used for storing extremely large quantity of information. These discs can be used to store pictures and sounds. Following the instruction one or more tasks can be performed. Traffic lights, washing machines, calculators, lifts and watches etc are operated by single programs microprocessors. However, microprocessors installed in a computer can process simultaneously a number of programs. Several tasks can be performed at the same time.

The nature of the tasks could be the following:

- Word processing
- Data managing
- Graphic designing

Word processing

Using the word processing program, a user can type a word with the help of the keyboard. The word appears on the screen of the monitor. The user can correct his mistakes. He can add and delete new words, sentences and paragraphs. When the user finishes his typing, he can get a print out of his work on a paper. He can send his typed write-up to another computer. He can save his work on the compute disc.

The special usefulness of the word processing capability is that multiple copies of the document, typed only once, can be obtained by a single command. The copies can be sent to other computers, which may be far away from the typist's computer. Retyping of the document is not needed.

Graphic Designing

Using graphic designing program, various type drawing can be drawn on the screen of the monitor, which is connected to a computer.

The input device, mouse, is used for the drawing. Instead of a mouse, graphics table can also be used for design drawings.

There are a number of advantages of drawings and designs prepared by using computers and graphic designing. For drawing a faultless and perfectly round circle or other geometrical shapes, it is not necessary to use some special geometrical instruments. Using graphic programs, it is quite easy to draw scale drawing, image in mirrors and copies of already existing drawings.

Various colors can be filled in a prepared design. Some graphic programs exhibit three dimensional view of pictures and designs. The designs can be viewed from different angles by rotating it around an axis.

Data Managing

Database is, in fact, the bank of information or the base of the data. A file is stored in the database. Every file has a name, address, telephone number and other identification features. Information is safely stored in a file. Data managing program or software can quickly search and find a particular data. The software program can easily update, delete, store, retrieve and print data.

In many organizations such as schools and hospitals, the data managing programs are used to organize all information about the organization. Super markets label their goods and products with code bars. The code bars are, in fact, a sequence of digits, which indicate the price, make and other information about the goods. These code bars can be scanned by means of optical scanners. At the place of cash register, the bar codes are decoded by means of a laser beam. A central computer can prepare the bill for all the sold objects.

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Fig. 20.12 Code bars and their scanning

20.4. Handling Information.

There are about 10 billion nerve cells in the human brain. These cells are connected together and can exchange information with one another at the speed of about 420km/hr. They process information throughout the human body. Keeping in view the efficiency of human brain, scientists have invented different devices, instruments and methods for handling and processing quickly huge amount of information. Most of the instruments make use of micro-processors for handling information.

Microprocessor comprises of several electronic circuits. These circuits are prepared in the form of printed circuits on a tiny and thin chip of silicon or germanium. These circuits monitor a set of instructions or program.

Now a days, while setting at home one can handle accounts with bank on a telephone. Making use of data managing programs, one can check one's bank balances and can transfer money from one bank to another. When we punch our bank identity number on the keyboard then the compute installed at the bank recognizes this identity number and processes the information received according to the given instructions.

Monitoring, Tracking and Controlling

Computers are used to monitor the state of traffic. They are used to watch vehicles on roads control air traffic of aeroplanes and ships in the seas. Traffic signals installed on road crossings are linked together through computers. Traffic detectors are installed on road junctions to monitor the number of vehicles. The information received from various traffic junctions are sent to a computer controller, which regulates the green, red and yellow light installed at traffic crossings.

Monitoring and warning systems are installed on highways and motorways. The systems use sensors, which point out the traffic jams that may have arisen due to traffic accident or fault developed in vehicles. The drivers on the highways are informed in advance by means of boards and panels fixed on roadside as where is the traffic jam. Make use of satellites, the location of aeroplanes, buses, taxies and guidance for their routes can be continuously carried out.

With the use of satellite traffic system, the rate of air traffic has become double as compared with radar traffic system.

Using traffic tracking system, the arrival and departure times of passenger coaches and commuter buses can be checked.

SUMMARY

Information technology (IT) is based on modern science and technology Information can be sent quickly to long distances by means of IT.

There are various instruments or devices for storing information: large amount of information can be stored by using different methods and devices

Making use of different kind of instruments, information is handled in a particular manner for different tasks.

Making use of IT, electrical signals are transmitted by means of wires, radio waves in air and optical fibers to far distant places.

The major methods of storing information are the following:

Digital audio tapes, video cassettes tapes, compact discs, hard discs and optical discs.

Information is handled by different methods. For example, word processing is an example of handling information.

Graphic designing can be used to draw drawings and design graphics.

Using data managing programs, a large extensive data of information can be processed in the following forms.

To make file; update data; organize, process, sort and retrieve and print data.

Traffic monitoring, tracking and controlling traffic can be done by data managing programs.

QUESTIONS

1. Fill in the blanks.

i. Presently, we say that the whole world has become a small ______ village.

ii. IT is that technology that _____, ______ process and transmits information.

iii. Information can be converted to_____ signals and ______ waves

iv. Light signals are sent through ______.

v. The device which converts sound into electrical signal is called ______.

vi. In a mobile telephone, there is installed a small ______.

vii. The loudspeaker at the earpiece of a telephone converts ________ to ________.

viii. A fax machine converts a document into ________ .

ix. In a compute network, computers are ________.

x. A microprocessor ________ a set of instructions.

2. To what processes and stages information is passed in IT

3. What are the communication instruments that uses the following methods in receiving information:

   (a) Electrical signal (b) light signal (c) radio waves

4. Name two devices that stores information in

   (a) Magnetic form (b) a computer data

   (c) a form that can be read with laser beam

5. Give three methods of handling information.

6. What are the methods of storing information: Name the storage instruments.

7. What role can IT play in traffic control.

8. Write a short note on graphic designing.

9. Write a note data managing programs.

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